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Selective Automatic Extinguisher for Computer Cabinets Class A, B, or C with Notification (SAFECOMP)

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Currently, fire protection in electronic and computer facilities is provided by full flooding HALON or water sprinkler systems. An original, compact, smoke detector automatic extinguisher and alarm unit for local extinguishment of computer or electronic cabinets is described. An acoustic receiver which detects the alarm and provides fire department notification is also described. Environmental, component and system testing is discussed and test data presented.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, at the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico, under Contract F29601-84-C-0080, Job Order Number 21043014, for the Engineering and Services Laboratory, Headquarters Air Force Engineering and Services Center (AFESC/RD), Tyndall Air Force Base, Florida 32403-6001. Partial funding was provided by NAVAIR, Air 5511T, Jefferson Plaza 2, Room 1164, Washington DC 20361.

This report summarizes work done between October 1984 and February 1986. HQ AFESC/RDCF program manager was Mr Joseph L. Walker, and Mr Bryce E. Mason was the project manager. NAVAIR Fire Protection Technical Manager was Ms Phyllis Campbell.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

OBJECTIVE

The objective of this effort was to design, construct, test, and evaluate a capsulized device capable of selective, unsupervised extinguishment of Class A, B, or C combustibles in electronic/computer cabinets with automatic activation of a fire department notification system.

BACKGROUND

Total flooding halon and water sprinkler fire suppression systems are in general use for the protection of buildings and critical electronic equipment. Although these systems provide ample fire protection against total loss and large-scale damage, they are expensive to install and maintain. It is desirable to detect and suppress fires at the incipient stage without the release of a large quantity of expensive or potentially damaging agents and without damage from heat and smoke. For this reason, a small economical extinguisher system that can be easily installed for local detection and fire suppression has a large potential application.

Small fires in computer cabinets are a major cause of damage in computer facilities. The need exists for an economical capsulized device to detect and extinguish fires in their incipient stages. Such a device, coupled with a local alarm and a fire department notification system, would provide a versatile and inexpensive fire protection system. The system could provide protection where total flooding systems do not exist and could also be used where local fire suppression would save the unnecessary activation of a total flooding system.

This work is a follow-on task to the capsulized extinguisher for waste receptacles (SAFECAN). The data from the previous technical report: "Selective Automatic Fire Extinguisher for Class A with Notification (SAFECAN)," ESL-TR-83-07 Volumes I and II (Reference 1) was used extensively and is referenced in this report.

SCOPE

The development effort was divided into three phases:

Phase I

a. Literature and manufacturer's search for existing solutions, partial solutions, and potentially useful components.

b. Generation of a variety of conceptual designs.

c. Evaluation of concepts and components, including limited functionality testing.

d. Recommendation of the most promising concepts.

Phase II

a. Development of overall test plan.

b. Testing and observations to define environment.

c. Testing and refinement of device components.

d. Refinement of conceptual designs, initial prototype construction, and testing.

e. Recommendation of final designs.

Phase III

a. Final engineering and construction of prototype systems.

b. Evaluation testing of prototype units, including performance and reliability measurements.

c. Final cost analysis and recommendations.

This plan provides a go/no-go decision point for the continuation of the effort based on the success/risk at the end of each phase. The plan also provides for the modification or refinement, based on the research performed, of task definitions for successive phases. For example, a smoke detector was added to the effort toward the end of Phase II.

RECOMMENDED DESIGN

The recommended design consists of a capsulized extinguisher, smoke detector, acoustic alarm and remote acoustic alarm receiver which is connected to the central fire alarm system. Figure 1 is an illustration of the extinguisher/alarm unit. The unit consists of an aerosol-type can of Halon 1211. The canister bottom flexes under the halon pressure so that when the can is empty, it gives an empty indication by moving a small switch contact. The top of the aerosol can is sealed with a metal diaphragm or cap. The bursting pressure of this cap is such that the halon can be released in one of two ways. Under normal conditions, the release method is by an electronically activated puncture cartridge. The halon can also be released through the fail-safe rupturing of the cap at a pressure of 150 lb/in^2, which, for Halon 1211 is a temperature of approximately 180°F.

The puncture-actuating cartridge is powered by a 9-volt battery which also powers the smoke detector and electric buzzer. The ionization-type smoke detector detects the smoke and sounds the alarm (electric buzzer). After a predetermined delay, power is applied to the actuator cartridge. The heat generated by the 300 mA current through a hot wire will ignite the chemical in the cartridge, creating pressure that drives a piston to rupture the metal diaphragm (cap). This actuating cartridge operates in 10 ms and provides a force of 20 pounds. The cartridge is classified nonhazardous by the Department of Transportation, and is a readily available stock item. When the metal diaphragm ruptures, the halon discharges through the nozzle in approximately 10 seconds. Figure 2 is a block diagram of the system.

The electric buzzer provides local warning as well as signaling to the remote alarm receiver. The alarm receiver is mounted on a wall or ceiling remote from the extinguisher. The receiver recognizes the alarm signal based

Figure 1. SAFECOMP Actuation Concept.

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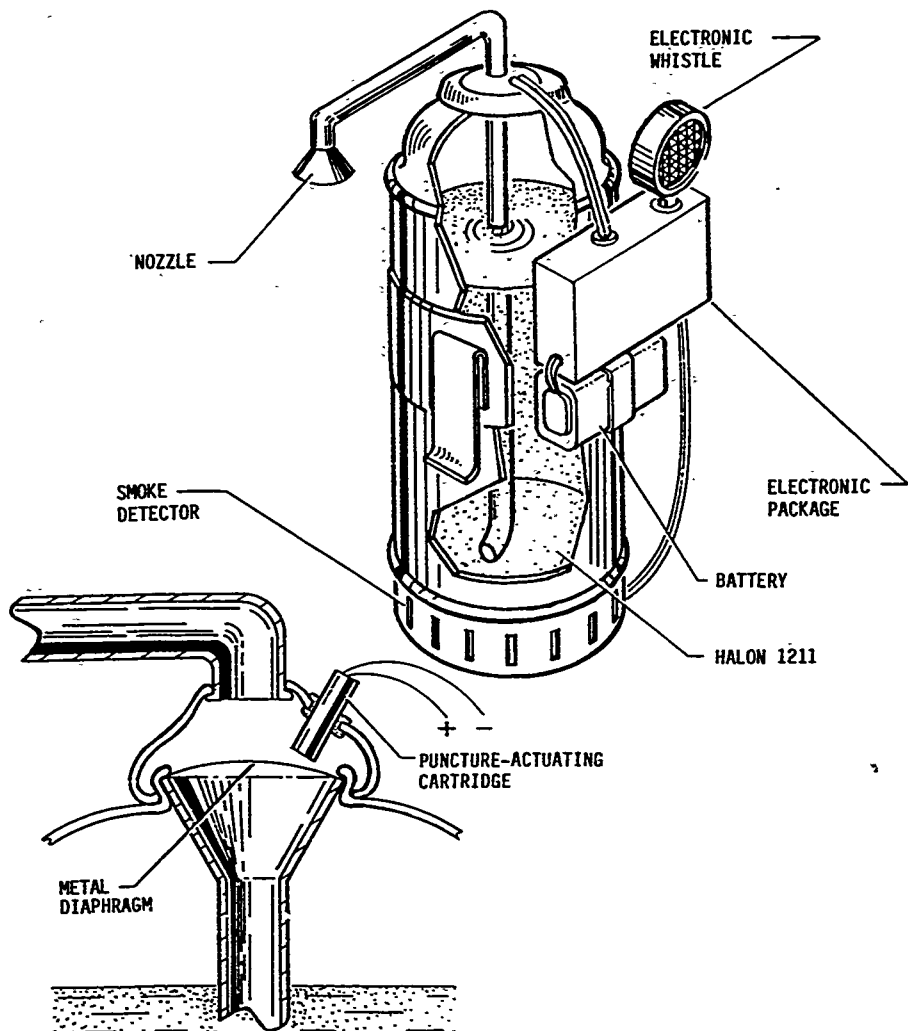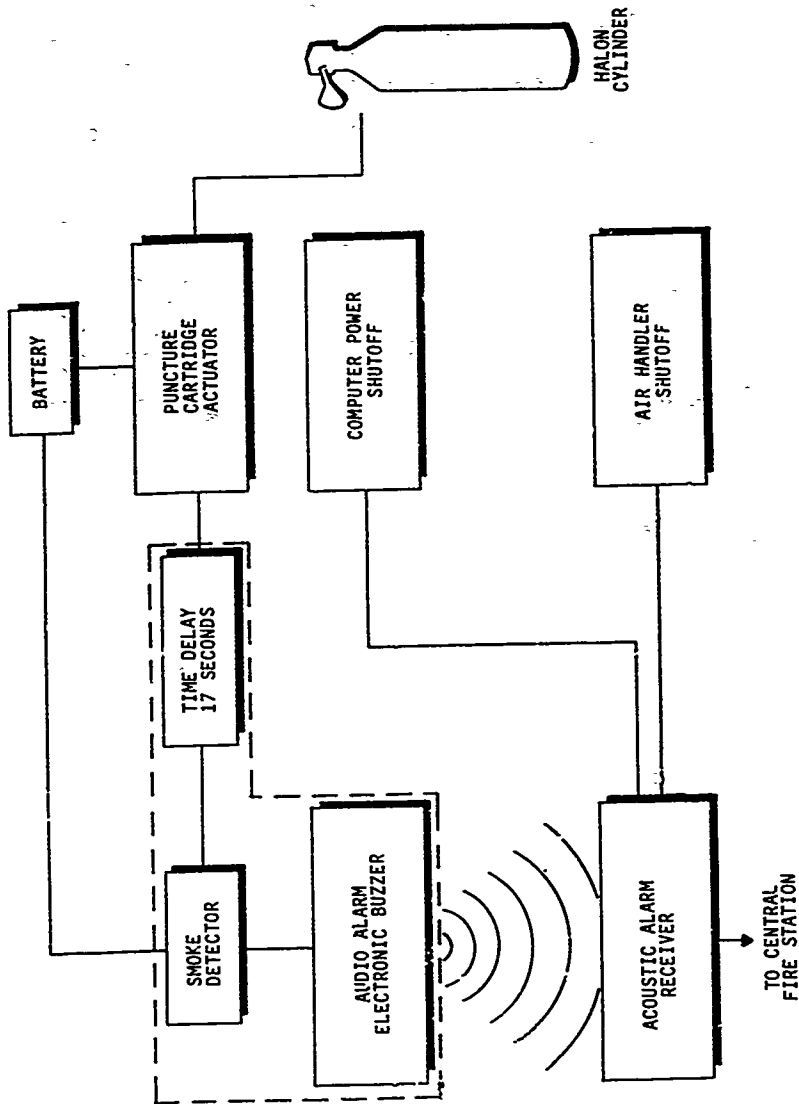
Figure 2. SAFECOMP Block Diagram.

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on the signal's frequency, intensity, and duration. Once a true alarm signal is determined, the receiver actuates an alarm signal to the central fire department and energizes relays to turn power off to the computer system and computer room air handler.

Details of the alarm and receiver designs are presented in Appendix B. This extinguisher system is called SAFECOMP, derived from Selective Automatic Fire Extinguisher for Computers.

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ENVIRONMENT

It is desired to extinguish a computer cabinet fire in the earliest, most reliable, efficient, and economic manner. Computer cabinet fires are caused by overheating from an electrical current or voltage surge. Testing of materials found in computer cabinets revealed that transformers, certain types of insulation, and printed circuit boards were the most combustible. The testing showed that electrical fires were low-temperature fires with large quantities of smoke for long durations prior to ignition. National Fire Protection Association (NFPA) literature (Reference 2) substantiated these conclusions. A modified SAFECAN was the initial concept pursued; but, because of the low heat and large quantity of smoke associated with a computer cabinet fire, the SAFECAN concept was abandoned as unfeasible. The results of quantitative environmental measurements are presented in Section III.

DESIGN OBJECTIVES

Six major design objectives were imposed on the SAFECOMP system from its inception. These objectives helped define and limit the range of potential designs.

The first objective was that the system would be small enough to fit inside almost all computer cabinets. Criteria for maximum system size were set at 4 inches wide by 5 inches deep and 10 inches long. The second objective was that the unit be self-powered and self-contained. These requirements implied no wiring or plumbing harnesses. If possible, no battery would be used. A third objective was that the unit would extinguish Class A, B, and C fires, thereby limiting the potential extinguishing agents. The fourth objective required the device to provide unsupervised extinguishment, implying completely automatic operation. A fifth objective required that the unit provide control signals to remotely activate an alarm to the fire department and shut off the computer and air handlers.

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The last objective required that the cost of an individual extinguisher/ alarm unit not exceed $25 based on a production run of 10,000 units. The ramifications of the $25 limit were the elimination of (1) expensive sensors such as optical, gas analysis, and thermal analysis; (2) nonintegral valves; (3) exotic materials; and (4) complex electronics.

OPTION ANALYSIS

Five fundamental functions that must be performed by any SAFECOMP design were identified. These functions are:

1. Fire detection

2. Agent release

3. Fire suppression (agent type)

4. Agent storage (container size, material, and mounting)

5. Alarm (local and remote)

Numerous potential methods of performing each of these functions exist. A literature review of publications was conducted, and solutions from the fire protection industry were solicited. The design objectives, particularly the remote alarm coupling and the cost objectives, severely limited the existing technologies applicable to this effort. Capsulization of the extinguisher and alarm into a reliable and economical package required essentially original work. The options identified during this effort for accomplishing the five functions listed above are presented and analyzed in the following sections.

Fire Detection

The first event for any fire-extinguishing system is for the fire to be detected. The best sensors are those that can detect the fire most rapidly, reliably, and economically. The sensor must be able to generate a signal of sufficient magnitude to release the extinguishing agent. The general categories of detectors are:

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a. Heat detectors

    (1) Thermocouples, thin films, etc.

    (2) Bimetallic or metallic

    (3) Electrical conductivity

    (4) Fusible alloy

    (5) Liquid or gas expansion

    (6) Rate-of-rise via pneumatic or thermoelectric effect

b. Smoke detectors

    (1) Ionization type

    (2) Photoelectric type

c. Flame detectors

    (1) Infrared

    (2) Ultraviolet

No single detector listed above will always be the quickest to respond to all fires. For instance, a smoldering fire will yield smoke long before a large emission of radiation, therefore a smoke detector may be the quickest; in contrast, a highly flammable liquid would almost immediately yield a large quantity of radiation that is rapidly detected by a flame detector. A heat detector may not respond as quickly as a smoke detector to a smoldering fire, or as quickly as a flame detector to a liquid fire, but it could provide moderately fast response to both types of fires as the heat of the fire approaches a dangerous level.

The selection of a fire detector depends on: (1) the space to be covered, (2) the types of fires anticipated, (3) the response required, (4) the detector's reliability, (5) its durability, and (6) cost. By definition in this effort, the space to be covered is 20 and 80 cubic feet of confined space, i.e., inside a computer cabinet. The type of fire anticipated is a long-smoldering fire. It is anticipated that the most common cabinet fire will be caused by the slow heating from an electrical overload. Therefore, the

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detector response speed need not be extremely fast. The cost of the detector and the balance of the extinguisher/alarm unit should not exceed $25.

The fact that electrical fires smolder for a long period of time before ignition, and burn at low temperatures after ignition, heat and flame detectors are not considered suitable for SAFECOMP application. Smoke detectors, which are commercially available and inexpensive, were considered the only viable type of detector for this application. Both ionization- and photoelectric-type smoke detectors, as well as a photoelectric/ionization combination detector were tested. All worked quite well and the ionization detector was chosen for SAFECOMP application.

Agent Release

Once a fire is detected by the smoke detector, a method of releasing the agent had to be found. The existing SAFECAN fusible link method was determined unsatisfactory because of the low temperatures associated with electrical fires. The ideal choice would be a mechanism activated by an electrical control. Several possibilities included: (1) a solenoid valve, (2) a solenoid-puncturing device, (3) an electrically heated bursting device, (4) a squib, and (5) a pyro-pneumatic rupturing device. The optimal solution would be small, inexpensive, low-powered, and safe. Ideally, the battery that powers the smoke detector would also actuate the agent release mechanism. The first three concepts above required large power supplies. The solenoids were bulky and the solenoid valves were expensive. The squib device is considered hazardous by the Department of Transportation. The pyro-pneumatic (cartridge) rupturing device is small, nonhazardous, inexpensive, and requires minimal power.

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Fire Suppression

The general categories of extinguishing agents are:

a. Water

b. CO_2 and inert gases

c. Foams

d. Dry chemicals

e. Halons

f. Others

Water, CO_2, inert gases, and foams are inappropriate because of the quantities involved. Dry chemicals are more appropriate for liquid-fueled and directly accessible fires. Other agents are inappropriate because of cost, availability, and/or lack of performance data. Halons are most appropriate because of the small quantities required and their ability to find their way through a semiblocked entry. As in the SAFECAN, Halon 1211 was chosen as the best choice. (See Reference 1, Volume I, page 11.)

Agent Storage

The size of the extinguishing agent container is primarily determined by the amount of agent needed to suppress a fire and the structural requirement for strength and durability. As an example, consider the volume requirements for Halon 1211 as stated in the NFPA Standard 12B (Reference 2), a nonconservative requirement for this application. The nominal quantity of Halon 1211 is 5 percent for many liquid fuels and flaming solids. This concentration may be required for a period of time. The computer cabinets investigated ranged from 6- to 71-cubic feet (Table 1). From Table 2-5.2 in Reference 2, the Halon 1211 weight requirements per cubic foot of hazard volume (pounds per cubic foot) is 0.0234 at 70°F and lower at higher temperatures. Therefore,

$$\frac{W\text{--lb agent}}{.0234} = V\text{--ft}^3 \text{ protected volume}$$

so for 1 pound of Halon 1211, $V = 1 \text{ lb}/0.0234 \approx 42.7 \text{ ft}^3$ of computer cabinet protection. The liquid density of the Halon is 1830 kg/m^3 at 20°C (1.82 g/l =

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TABLE 1. SPERRY 1100 COMPUTER SYSTEM CABINET VOLUME.

Cabinet Description	Dimensions L x W x H, in.	Cabinet Volume, ft
CPU 3042	61 x 31 x 65	71.1
1-DCP-40 Comm Prcssr	43 x 31 x 65	50.1
5056 Disc Contrlr	54 x 31 x 65	63.0
8433 Disc Drive	31 x 20 x 36	12.9
8470 Disc Drive	33 x 25 x 42	20.0
SSP (sys sprt processor)	30 x 14 x 25	6.1
8480 Disc Drive	60 x 31 x 65	70.0
Disc Drives 8408	20 x 30 x 39 Small	14.9
7053 Cache	36 x 31 x 65	42.0
7049 External Memory	36 x 31 x 65	42.0
776 Printer	37 x 31 x 57	37.8
5058-12 Tape Drives	43 x 31 x 65	50.1

114.4 lb/ft^3). To contain 1 pound of Halon, the volume required is
(1 ft^3/114.4 lb) x 1.0 lb x (1728 in^3/ 1 ft^3) = 15.1 in^3. This requires a
cylinder of 2.5 inches in diameter by 3.1 inches in length. One pound of
Halon 1211 was chosen as a standard size unit. Cabinets greater than 42.7 ft^3
would require more than one unit. The most economic choice for the container
which would be used to hold the extinguishing agent is an aerosol-type metal
can.

When halon is heated, it generates pressure (its vapor pressure). If
Halon 1211 is heated to 150°F, the vapor pressure is approximately 125 lb/in^2,
absolute. Therefore, the container must withstand significant pressure. The
aerosol-type cans provide a maximum strength of 270 lb/in^2, with a maximum
working pressure of 180 lb/in^2. The metal diaphragm-rupturing cap would be
designed to rupture at 150 lb/in^2.

Alarm

Although the SAFECOMP must automatically detect and extinguish computer
cabinet fires, it must also perform other more important functions, that is,
local alarm, and alarm telemetering. These functions are important for two
reasons. First, they alert personnel in the immediate vicinity to the possi-
bility of imminent danger. Second, they offer alternate extinguishment
options (i.e., fire department or local personnel action) should the SAFECOMP
fail to completely extinguish a smoldering fire. To accomplish these objec-
tives the alarm must be reliable, economical, and compatible with the rest of
the SAFECOMP unit. The previously stated design objectives apply to the alarm
as well as the extinguisher functions. Alarm telemetry considerations in this
effort ended at the interface to a power shutdown relay and a standard central
alarm system assumed to exist wherever notification to the fire department is
desired.

An electric buzzer to transmit an acoustical signal was the logical
choice since battery power was available for the smoke detector. Advantages
of this system include reliable signal detection, easy functional testing,
large-area coverage, small and durable packaging, and low cost.

INITIAL CONCEPTS

Before conducting fire tests in computer cabinets, the first choice was to modify the existing SAFECAN design. Figures 3 to 5 show original concepts of the modified SAFECAN for SAFECOMP application. Smoke detectors were investigated after fire tests proved that smoke (not heat) was the appropriate means for fire detection. The use of a battery-powered smoke detector simplified the design and construction of SAFECOMP while increasing the reliability of the unit.

Figure 3 shows the original SAFECAN along with two pressurized and two nonpressurized concepts. The two nonpressurized concepts use a halon gas powered whistle for the alarm function. A fusible link sliding plug was developed and tested. The sliding plug allows the halon gas to pass through the whistle while the halon liquid exits through the nozzle. The nozzle tube extends to the bottom of the can. The whistle tube ends at the top of the can. Figure 5 shows the details of this concept clearly.

One of the pressurized concept functions exactly like the nonpressurized concepts, but is super-pressurized with nigrogen. The other pressurized concept uses a small nitrogen cartridge to provide pressure to the halon canister. The mousetrap design (Figure 4) is used to puncture the nitrogen cartridge. The fusible link releases the halon and allows the trigger rod to move.

Further testing verified that Halon 1211 has sufficient pressure to give adequate dispersion in the computer cabinet. Therefore, the pressurized concepts were abandoned.

NON-PRESSURIZED CONCEPTS

GLASS BOTTLE

AEROSOL CAN

SAFECAN

PRESSURIZED CONCEPTS
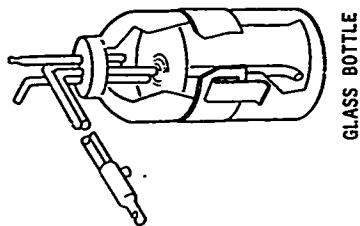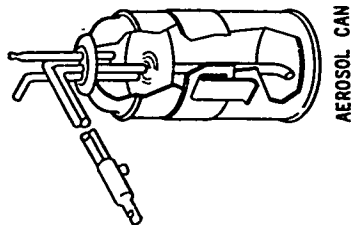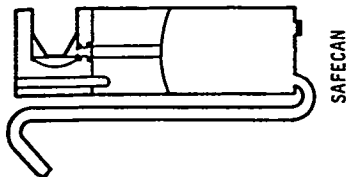
MOUSETRAP

PRESSURIZED AEROSOL CAN
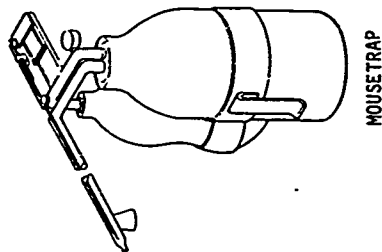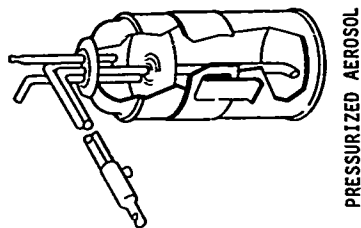
Figure 3. Modified SAFECAN Concepts.

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SLIDER PLUG

SPRING-LOADED TRIGGER ROD

"MOUSETRAP"

WHISTLE

NOZZLE

NITROGEN CARTRIDGE

SUSPENSION CLIP

COMPUTER CABINET

PLASTIC COATING

HALON BOTTLE

ONE WAY VALVE
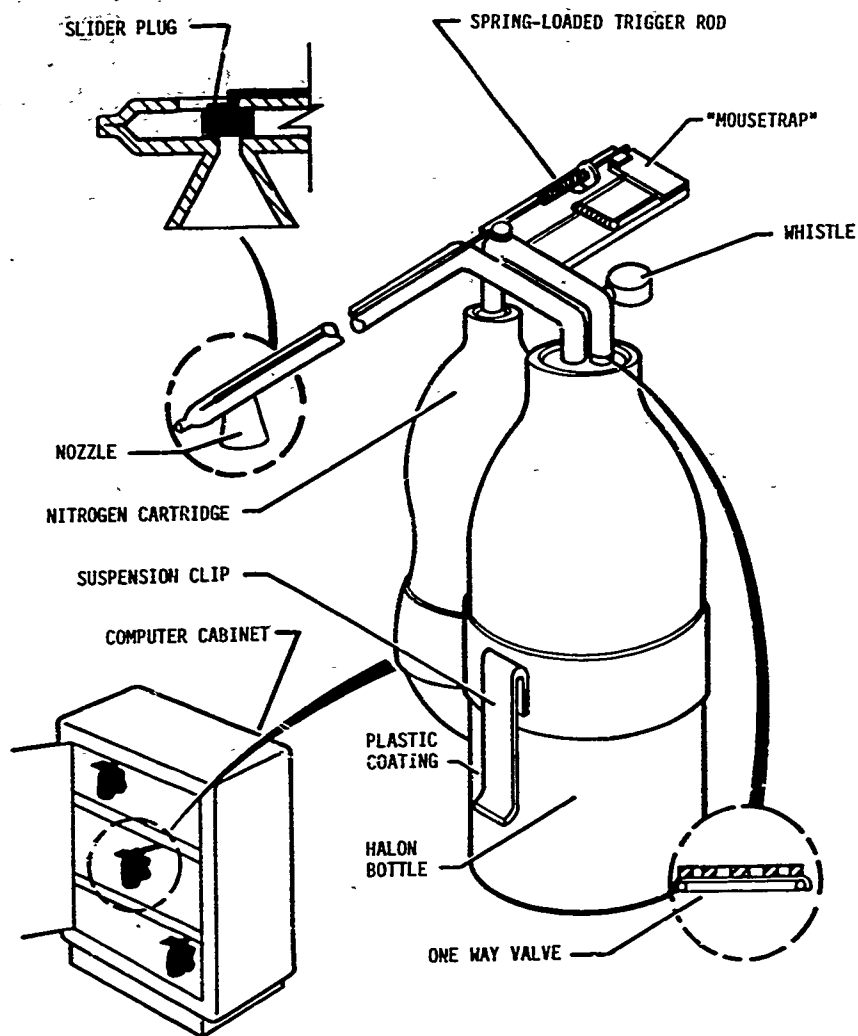
Figure 4.   SAFECOMP Mousetrap Concept.

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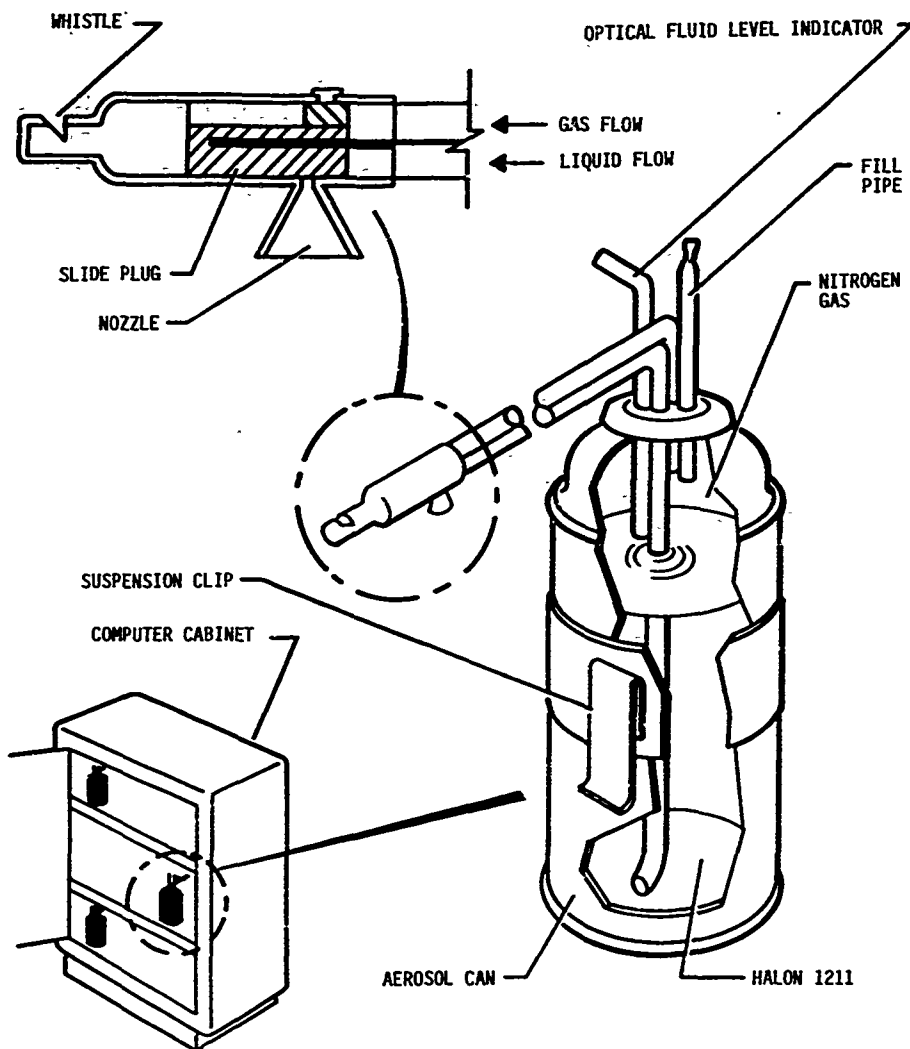
Figure 5. SAFECOMP Aerosol Can Concept.

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SECTION III
TEST PROGRAM

TEST PLAN OVERVIEW

SAFECOMP development and evaluation testing was separated into the three categories shown in Table 2. The Environmental Tests (Category I) were used to quickly verify concepts, uncover unforeseen effects, and quantitatively define the environment in which the SAFECOMP must operate. Component Tests (Category II) allowed a quantitative comparison of SAFECOMP component performance and design options. System Evaluation Tests (Category III) were conducted to demonstrate the repeatability, durability, and performance of the final SAFECOMP design. Table 2 lists the tests that were conducted within each category.

TABLE 2. TEST PLAN STRUCTURE.

CATEGORY I: Environmental Tests
    Combustible material
    Temperature profiles
    Environmental noise
    Air flow in computer cabinets
    Exploratory design tests

CATEGORY II: Component Tests
    Fire detection
    Agent release
    Agent storage
    Alarms
    Alarm receiver

CATEGORY III: System Evaluation Tests
    Extinguisher/alarm subsystem
    Toxicity
    System Evaluation Test Plan
    Test Results

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Although the tests were conducted somewhat sequentially, proceeding from Category I through III, there was a large degree of overlap between various categories. Testing of the most promising concepts received the highest priority. Environmental data provided by the SAFECAN report (Volume II) was used extensively. All testing was conducted by the New Mexico Engineering Research Institute (NMERI). Equipment used during the test program included a Panasonic color video camera and video recorder, a multichannel Acurex Autodata Ten/5 calculating data logger with type K thermocouple sensors, Mine Safety Appliance (MSA) sound level meter, a Bruel and Kjaer (B & K) type 2209 precision sound level meter with 1613 octive filter set, an Alnor velocity gage, Nicolet 3091 digital storage oscilloscope, B & K type 1024 Noise Generator and miscellaneous electronic equipment such as sine wave generator, frequency counter and digital multimeters.

TEST DESCRIPTIONS AND RESULTS

This section describes the tests listed in Table 2. Reasons for conducting the tests, the method of accomplishing the tests, and conclusions indicated by test results are presented. Complete test data are provided in the appendixes of this report.

Category I: Environmental Tests

Combustible Material

Several types of materials found in computers were burned to test their flammability. These included wire insulation, printed circuit boards, capacitors, and transformers. The transformers proved to be the most flammable and were used for the temperature profile tests.

Temperature Profiles

The purpose of these tests was to determine temperature ranges, distributions, and time histories of typical computer fires. This information was used to establish response criteria, safety criteria, and detector location for SAFECOMP. Transformers with shorted secondary windings were used in these tests.

Temperature readings were recorded at short intervals from six locations around the transformer using the automatic data logger. Appendix A

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includes all the results of these tests. In three of the tests, a SAFECAN fusible link was located directly over the transformer. In none of the tests was the heat from the transformer fire sufficient to melt the fusible link solder. The basic conclusions drawn from the test results are: (1) transformers produce large quantities of smoke at low temperatures during the fire's incipient stage and, (2) smoke detection would be preferred over heat detection.

Environmental Noise

The purpose of this test was to determine the acoustic environment in which a sonic alarm would have to operate. The acoustic signal produced by SAFECOMP must be distinguishable from the background noise present in computer facilities which was found to be typically 65 dB.

Tests were conducted under the previous SAFECAN program. Noise recordings were taken at 17 locations in three computer facilities: the University of New Mexico (UNM) computing center, the Air Force Weapons Laboratory (AFWL) computer center, and the AFWL Data Conversion Branch (ADDE) computer room. Refer to SAFECAN Technical Report ESL-TR-83-07 Volume II, Appendix C, page 133.

Air Flow in Computer Cabinets

Air flow measurements were made on computer cabinets at the Air Force Data Processing Center, Kirtland Air Force Base. The Alnor velometer was used to obtain the measurements. Measurements were taken at the cabinet exhaust vents. typically at the top of the cabinet. For the Sperry 1100 computer cabinets, the average output was 200 feet per minute (ft/min) and ranged from 75 ft/min to 450 ft/min. The tape drive average air flow was 120 ft/min. In the older Burroughs computer cabinets, the air output ranged from 120 to 800 ft/min, with the average output being 200 ft/min.

These data were used to assure realistic temperature profiles, component tests, and system evaluation tests for both fire detection and agent dispersal.

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Exploratory Design Tests

These tests provided a means of rapidly checking the feasiblity of design concepts (components or systems) and discovering unforeseen effects. The results of these tests were used to refine designs and test procedures in the following Category II and III testing.

During these tests, laboratory models were exposed to real work conditions, and their responses were monitored. The video recorder and other apparatus appropriate to a particular test were used to monitor and document the tests for repetitive reviews and evaluations. Tests using the original SAFECAN design and various modifications were conducted. When the temperature profile tests showed conclusively that heat detection was not feasible, the SAFECAN tests were abandoned. Tests were then conducted on ionization and photoelectric smoke detectors.

Category II: Component Tests

Fire Detection

The purpose of these tests was to evaluate the performance of various smoke detection devices. Three types of detectors from three manufacturers were tested. The photoelectric, ionization, and photoelectric/ionization detectors all performed well for the purpose and response time required for SAFECOMP. The ionization detector was chosen as the best candidate. Appendix C gives the results of the smoke detector response tests.

Agent Release

Tests were conducted to determine the time required to release the halon. Research indicated that a 10 second release time would provide a good extinguishing concentration and a safe toxicity level. The tests showed that this release time is obtainable with the SAFECOMP unit using Halon 1211.

Other tests were conducted to verify the performance of the diaphragm-puncturing cartridge. Three different types of cartridges were

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used; all three are manufactured by ICI, Inc. All three performed success-
fully in all tests. Two types utilize a flat puncturing edge with the only
difference being the current requirements: one requires 100 mA, and the other
requires 300 mA. The third device has a pointed puncturing edge.

Agent Storage

Many types of sealed canisters are capable of storing Halon
1211. However, the aerosol can chosen is the least expensive. For testing
purposes, a brass cannister which could easily be refilled was used. A dip
tube is required so that halon liquid (as opposed to gas) would be released.
This dip tube must be directed to the lower can side when the SAFECOMP is used
in the horizontal position. Testing revealed that with these design
considerations, good penetrating agent release would consistantly be delivered
to the computer cabinet. Figure 6 shows the components of the SAFECOMP test
unit. Figure 7 shows the assembled SAFECOMP test unit.

Alarms

The alarms tested were those provided with the smoke detector
units. All alarms were of the electric buzzer type. The alarms performed
satisfactory for the SAFECOMP requirements. The average decibel level was
85 dB at 10 feet. The alarm used for the SAFECOMP design is manufactured by
BRK Electronics. The alarm frequency is 3200 Hz.

Alarm Receiver

The alarm receiver block diagrams are shown in Figure 8. A
complete description and schematic diagram are contained in Appendix B. Three
prototype units were constructed and tested. Tests conducted include: alarm
filter center frequency, alarm filter bandpass width, simulated alarm detec-
tion without noise, simulated alarm detection with noise, simulated false
alarm detection, and alarm detection under actual conditions. The alarm
receiver performance under all tests was good. The test results under actual
conditions are discussed in the following section.
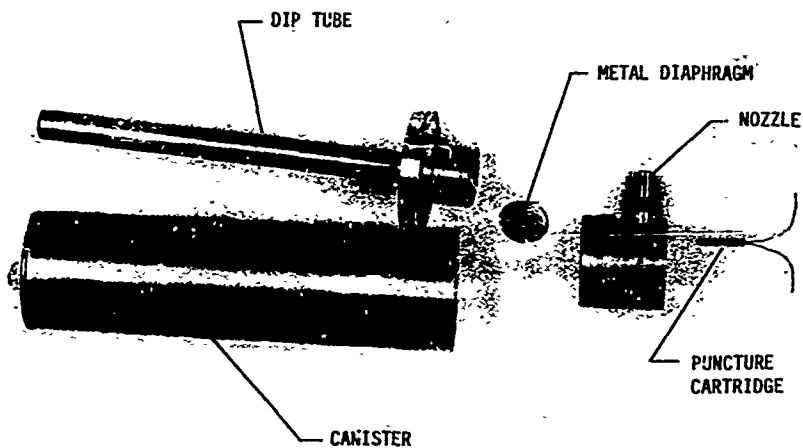
Figure 6. SAFECOMP Test Unit Components.
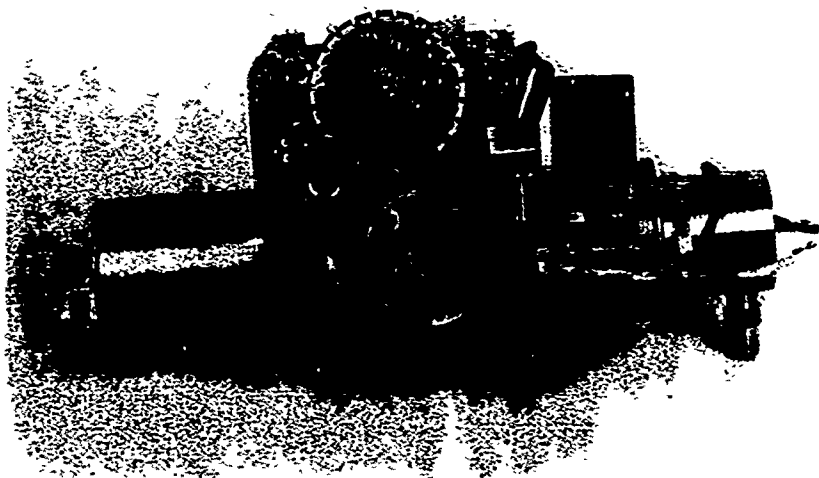
Figure 7. SAFECOMP Test Unit.
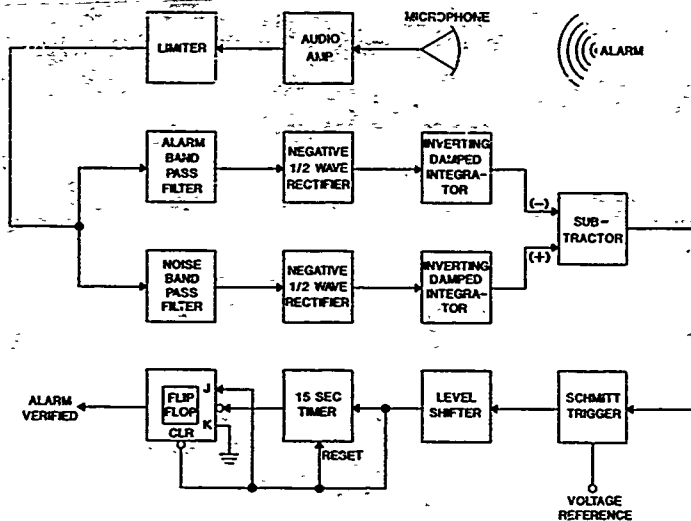
Figure 8. Alarm Receiver Block Diagram.

Category III: System Evaluation Tests

Extinguisher/Alarm Subsystem

SAFECOMP (Figure 7) is the extinguisher/alarm subsystem used in the tests. All tests of SAFECOMP were successful, indicating that the unit is quite reliable. Smoke detector sensitivity, alarm duration, diaphragm puncturing delay, and agent release time are variables that can be optimized. The smoke detector sensitivity was set to UL 217 requirements (Reference 4). The puncturing delay time was set at 17 seconds, and the halon release time was optimized at 10 seconds according to UL standards. The 17 second delay for diaphragm rupturing correlates to the 15 second time delay set on the alarm receiver to verify an alarm received. Two seconds are allowed for the blowers and computer power to be shutoff. Tests proved this to be adequate.

A 9-volt dc battery was capable of providing all of the electrical power for SAFECOMP: smoke detection circuitry, alarm generation, and puncture cartridge activation. Additional tests need to be conducted to verify a longevity of 1 year for the battery.

Toxicity

Toxicity tests were not conducted due to time and funding constraints. The toxicity testing accomplished in the SAFECAN program (Reference 1, Volume 1, page 56) is directly applicable to SAFECOMP. Since SAFECOMP temperatures are lower, the decomposition would be less, leading to the conclusion that SAFECOMP would be less toxic than SAFECAN.

System Evaluation Test Plan

The system evaluation tests were conducted at the computer fire test facility at Tyndall, AFB. The test plan is found in Appendix D. Only minor deviations were made from the test plan. Five tests were performed in three cabinets: Tests 1 and 2 in the processor unit, Tests 3 and 4 in the FASTRAND unit, and Test 5 in the tape drive unit. Tests 1, 3, and 4 used transformers as the smoke and fire source. Test 2 used a burning fuel cup,

and Test 5 used a burning fuel cup and a transformer. Other deviations from the test plan include: (1) velocity measurements of air flow in the cabinet were made prior to test and recorded manually, (2) the halon concentration instrumentation was disregarded because the response time was too slow to provide accurate readings, and (3) to increase data collection speed only thermocouples 00 through 04 were used. The distance the alarm receivers were from the alarm unit also differed from the test plan. In Tests 1 and 2, Receiver 1 was 8 feet away, Receiver 2 was 6 feet away, and Receiver 3 was 10 feet away. In Tests 3, 4, and 5, Receiver 1 and 3 were 25 feet away and Receiver 2 was 11 feet away from the alarm.

Test Results

In all five tests the SAFECOMP was capable of detecting and extinguishing the fire. The alarm sounded in every test and the alarm receivers verified the alarm in an ambient noise level of 76 dB. In two tests, one of the three alarm receivers failed to detect the alarm. In the first case, a microphone was inadvertently unplugged. In the second case, alarm Receiver 3 failed to detect the alarm because the sensitivity of the unit was set too high. Alarm Receiver 3, as well as alarm Receiver 1 were 25 feet from the alarm unit. Test number 1 (Appendix E--page E-3) is a typical result of the tests performed. Four of the thermocouples showed no temperature rise. Thermocouple 1 reached a maximum temperature of 91°F before cooling rapidly from the halon dispersion. Time $T = 0$ is when the smoke detector detected smoke and set off the alarm.

The time before $T = 0$ is the arbitrary starting of the data recording. Starting at $T = 0$, 20 one-second ticks are placed on the graph for timing reference. Points 4, 5, and 6 are when the alarm Receivers 1, 2, and 3, respectively, first detected the alarm. Points 1, 2, and 3 indicate that alarm Receivers 1, 2, and 3, respectively, timed the alarm and verified it as a true alarm. Point 7 is when the halon was released. In Test 1, alarm Receiver 1 detected the alarm in 1.8 seconds and verified the alarm (timed out) at $T = 15.8$ seconds. Alarm Receiver 2 detected the alarm in 0.7 seconds and verified the alarm at $T = 14.8$ seconds. Alarm Receiver 3 detected the alarm at $T = 2.0$ seconds and verified the alarm at $T = 13.8$ seconds. Simple subtraction shows the alarm receiver timers to be set at 14 seconds,

14.1 seconds, and 11.8 seconds. The detection times of the receivers is dependent on their sensitivity and their distance from the alarm. Point 7, the halon release, was at T = 18.8 seconds. This indicates that the RC time constant for the smoke detector was set at 18.8 seconds before power was applied to the puncturing cartridge. Test 1 results are representative of all of the tests. All five test graph results are included in Appendix E.

SECTION IV
CONCLUSIONS AND RECOMMENDATIONS

A fire protection system which automatically detects and extinguishes fires in computer cabinets, and provides local alarm and notification to the fire department has been designed, developed, and successfully tested. The system consists of a small, self-contained, capsulized extinguisher/alarm unit which mounts on or in a computer cabinet, and a remote alarm receiver which recognizes the local alarm and generates a signal to notify the fire department. The alarm receiver also provides a signal to disconnect the air handler and computer cabinet power.

The extinguisher/alarm unit is unobtrusive and will not interfere with the computer. It provides unsupervised extinguishment of Class A, B, and C fires within the computer cabinet using Halon 1211 as an extinguishing agent. The toxic products generated in the extinguishment process should not reach hazardous concentration in normal work spaces. The smoke detector, agent release, and acoustic alarm are powered by a single 9-volt battery. The extinguisher/alarm unit design offers the potential of unit costs less than $25, in quantities of 10,000 or more. Table 3 is an estimate of costs for the extinguisher/alarm unit in lot quantities of 10,000. Table 4 is the actual material cost to construct the prototype alarm receiver unit. This cost should be under $100 for the manufactured unit. Using the $17.95 figure for the cost of the extinguisher/alarm unit, and $100 for the alarm receiver unit, the SAFECOMP system is less than $25 per unit, if one receiver unit services 15 extinguisher/alarm units.

The environment noise tests from the SAFECAN program, and the acoustic coupling tests performed during this effort were intended to verify the acoustic coupling concept. This concept was successfully verified. The potential exists for extending the coupling range and improving the receiver's false alarm rejection capability; suggested refinements to the receiver circuitry are provided in Appendix B. Extensive measurements are needed to establish guidelines for installation of the SAFECOMP acoustic coupling system. Optimization testing should be performed to determine allowable range, optimum signal threshold settings, and optimum time-constant settings in a variety of acoustic environments if the system is to be utilized most effectively and economically.

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TABLE 3. EXTINGUISHER/ALARM UNIT--COST ANALYSIS.

Material/Component	Cost*
Aerosol Can	$ 0.20
Halon (1b)	2.50
Smoke Detector Alarm	8.75
Puncturing Cartridge	4.00
Metal Diaphragm (Cap)	0.20
9-Volt Battery	0.90
Dip Tube	0.10
Nozzle	0.45
Full/Empty Indicator Switch	0.35
Plastic Case	0.50
	$17.95

*Quantities of 10,000

TABLE 4. PROTOTYPE ALARM RECEIVER UNIT--COST ANALYSIS.

Material/Component	Cost
Electronic Components	$ 44.61
Microphone	6.95
Power Supply Module	72.71
4.5-inch x 9-inch Circuit Board	11.74
25-Pin Connector	5.25
	$141.26

REFERENCES

1. Wilson, C. W., Trujillo, T. M., and Zallen, D. M., Selective Automatic Fire Extinguisher for Class A with Notification (SAFECAN), Volumes I and II, ESL-TR-83-07, Air Force Engineering and Services Center, Tyndall Air Force Base, FL, December 1982.

2. NFPA Fire Incident Data Organization, Fires Involving Computer Equipment, National Fire Protection Association, Boston, MA, 1982.

3. ANSI/NFPA Standard 12B, Halogenated Extinguishing Agent System Halon 1211, National Fire Protection Association, Boston, MA, 1977.

4. ANSI/UL 217, Single and Multiple Station Smoke Detectors, Underwriters Laboratory, 1983.

APPENDIX A
COMPUTER CABINET FIRE TEMPERATURE PROFILES

OBJECTIVE

The following tests were conducted to determine the temperature of a typical computer cabinet fire during its incipient stage. Transformers were chosen to simulate the fires since they are one of the hottest self-sustaining fuel sources present in a computer cabinet. Various other components were tested including printed circuit boards, wire insulation, and capacitors. Transformers proved to be the most flammable computer component.

All tests were conducted with the transformer secondary winding intentionally shorted. A more representative test was previously conducted in which the transformer secondary was overloaded, but the results of these tests showed that the transformers smoked up to 50 minutes prior to ignition, and that the temperatures remained cool except immediately after ignition. Therefore, to expedite the temperature profile tests, it was decided to directly short out the transformer secondary windings. The transformers varied in size and capacity because they were obtained from salvage.

TEST RESULTS

The typical computer cabinet fire produces large quantities of smoke and low temperatures. Therefore, the heat detection device (fusible link) used in the previous SAFECAN design is not a viable method of fire detection for this application.

In tests 30, 32, and 34, a SAFECAN fusible link was located directly over the transformer. The 158°F fusible link solder did not melt in any of the tests, even when the temperature exceeded 158°F. The fusible link and nozzle thermal mass, combined with the short time duration, prevented the solder from melting.

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Thermocouple Locations

Unless stated otherwise on the following test charts, the temperature thermocouples were positioned with respect to the transformer as follows:

00: Inside secondary winding

01: Inside primary winding

02: 3 inches above secondary winding

03: 3 inches above primary winding

04: 12 inches above secondary winding

05: 12 inches above primary winding

Test numbering is not sequential because tests of different types were conducted in this sequence. The alternate tests are not appropriate for this Appendix.

Test Number: 6

Initial (Test Start) Time: 01:15:50

Start (Recorder) Time: 01:21:39

High Temperature: 988°F (Channel 04 At 69 Seconds)

Thermocouple Locations: 00: Inside secondary 01: Inside primary
02: Outside secondary 03: Outside primary
04: Under transformer 05: 3 in above transformer

Notes: Transformer ignited with flames 6 to 8 inches high. Flames died down when transformer popped circuit breaker.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time	b---	46	45	46	46	47
Start Time[a]	---	48	47	47	46	47
23	---	48	46	47	46	47
35	---	49	47	47	46	46
43	---	50	63	49	48	53
52	---	54	108	99	282	92
60	---	63	195	206	690	413
69	---	77	301	313	988	501
88	---	103	462	453	514	371
96	---	115	470	485	381	284
105	---	127	451	488	297	218
116	---	139	404	455	222	164
124	---	145	366	415	189	136
146	---	157	367	364	136	128
152	---	161	391	369	123	111
158	---	166	400	359	113	113
163	---	171	398	340	105	104
183	---	199	354	308	140	240
189	---	207	379	301	137	194
195	---	215	367	288	122	173

(Continued)

[a]Time starts from start (recorder) time.
[b]Channel indicated overrange.

Test Number: 6 (Concluded)

Elapsed Time, Seconds	Channels--Temperature, °F					
	00	01	02	03	04	05
200	---	223	368	279	111	160
206	---	230	375	272	101	150
212	---	236	377	262	94	150
217	---	242	395	250	90	149
223	---	247	394	239	86	135
225	b---	250	386	235	84	131
228	---	252	374	229	83	132
231	---	254	363	225	81	140
234	---	257	351	221	80	135
237	---	259	339	218	79	129
240	---	261	325	215	77	125
242	---	263	314	212	76	126
245	---	265	304	211	75	122
248	---	268	292	211	74	119
251	---	270	283	211	73	116
253	---	272	273	212	73	118
256	---	274	264	214	72	121
259	---	277	255	217	71	122

[a]Time starts from start (recorder) time.
[b]Channel indicated overrange.

Test Number: 7
Initial (Test Start) Time: [a]---
Start (Recorder) Time: [a]---
High Temperature: 280°F (Channel 01)
Notes: Small transformer used, no ignition.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
[a]---	[b]---	280	248	220	70	118

[a]Elapsed time not used.
[b]Channel indicated overrange.

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Test Number: 9
Initial (Test Start) Time: 03:58:28
Start (Recorder) Time: 03:59:39
High Temperature: 346°F (Channel 01 At 190 Seconds)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	61	61	62	62	63	63
3	61	61	52	62	63	63
Start Time	62	63	62	62	64	63
74	62	64	63	62	63	63
77	63	66	63	62	64	63
80	63	70	63	62	64	63
83	64	75	63	63	64	63
86	65	81	53	63	64	63
89	65	86	63	63	64	63
93	67	94	63	63	64	63
96	69	101	63	63	63	63
99	71	109	63	63	64	63
102	73	118	63	63	64	63
105	75	126	63	53	64	63
126	100	189	63	64	63	63
129	106	198	63	64	63	63
140	129	232	63	67	63	63
143	133	---	---	---	---	---
173	161	321	66	69	66	63
175	164	328	66	68	66	63
178	166	333	67	69	66	64

(Continued)

[a]Time starts from initial (test start) time

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Test Number: 9 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
181	168	338	66	70	66	64
184	170	341	67	70	66	64
187	172	344	66	70	66	64
190	173	346	67	70	66	63
223	186	343	67	71	66	63
226	187	341	67	70	65	63

[a]Time starts from initial (test start) time.

Test Number: 10

Initial (Test Start) Time: 04:17:05

Start (Recorder) Time: 04:18:27

High-Temperature: 495°F (Channel 01 At 255 Seconds)

Notes: New transformer (2 1/2 x 2 1/2 x 3 inches).
Primary rated at 115 Vac, 60 Hz.
Secondary rated at 12.6 Vac at 4A.

| Elapsed Time, Seconds | Channels--Temperature,°F | | | | | |
	00	01	02	03	04	05
Initial Time[a]	68	68	68	67	67	67
3	68	68	67	67	67	67
Start Time	68	68	68	67	68	67
85	68	68	68	67	67	67
88	68	69	68	67	67	67
91	69	70	68	67	67	67
94	69	73	68	67	67	67
97	71	78	68	67	67	67
100	72	83	67	67	67	67
103	75	90	68	67	67	67
121	150	154	68	67	67	67
133	117	115	67	66	67	66
136	101	106	67	67	67	66
198	114	323	68	69	67	67
205	116	342	68	68	67	67
208	118	---	---	---	---	---
222	125	387	68	67	67	67
236	131	430	68	67	67	67
239	132	440	68	67	67	67
242	134	450	68	67	67	67
246	136	462	68	67	66	67

(Continued)

[a]Time starts from initial (test start) time.

Test Number: 10 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
248	138	472	68	67	67	67
251	139	485	68	67	68	57
255	142	499	68	67	67	67
258	143	474	68	67	68	67
260	144	383	68	67	68	67
263	145	321	68	67	67	67
266	146	273	68	68	67	67
269	149	235	68	68	67	67
272	152	209	70	69	67	67
275	155	183	73	71	67	67
278	158	165	75	74	67	67
281	162	148	78	79	68	67
284	166	134	81	79	67	67
287	170	124	83	77	67	67
290	173	116	82	75	67	67
293	177	109	81	74	67	67
296	180	102	79	73	67	67
299	188	97	78	72	67	67
302	195	93	76	71	68	67

[a]Time starts from initial (test start) time.

Test Number: 11
Initial (Test Start) Time: 04:51:30
Start (Recorder) Time: 04:53:55
High Temperature: 726°F (Channel 03 At 18 Seconds)
Notes: New transformer (4 x 5 x 4 1/2 inches).

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Start Time[a]	68	68	72	142	69	69
6	68	75	82	246	80	71
12	68	93	97	583	105	77
18	68	120	96	726	116	76
24	68	143	97	723	125	75
30	68	174	96	683	121	75
36	68	219	100	680	116	75
42	68	252	103	637	120	76
48	68	276	103	577	125	77
[b]54	69	293	155	644	113	76
60	70	307	371	638	106	77
66	70	316	328	515	98	75
72	70	321	294	435	93	74
78	71	322	276	385	88	73
84	72	319	306	416	85	73
90	72	313	321	443	83	74
96	74	305	388	474	81	73
102	77	297	665	591	80	74
108	77	288	543	475	78	73
114	77	278	459	395	77	73

(Continued)

[a] Times start from start (recorder) time. All channels registered 67° to 68°F before start (recorder) time.

[b] Chassis cover placed 5 inches above transformer at 54 seconds.

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Test Number: 11 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
120	78	268	394	344	76	72
126	78	259	350	307	75	72
132	79	250	333	337	74	72
138	79	241	333	373	73	73
144	80	233	355	400	74	74
150	81	224	378	377	74	74
156	82	217	469	348	75	74
162	83	210	413	316	75	74
168	84	204	365	298	75	74

[a]Times start from start (recorder) time. All channels registered 67° to 68°F before start (recorder) time.

[b]Chassis cover placed 5 inches above transformer at 54 seconds.

Test Number: 12
Initial (Test Start) Time: 01:31:49
Start (Recorder) Time: 01:33:56
High Temperature: 658°F (Channel 00 At 3428 Seconds)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	67	67	66	67	68	70
3	69	---	---	---	---	---
Start Time	69	68	67	66	67	66
129	69	68	67	66	67	67
132	69	68	67	66	67	67
135	69	68	67	66	67	67
138	69	68	67	66	67	66
141	69	68	67	66	67	67
144	69	68	67	67	67	67
147	69	68	67	67	67	67
150	69	68	67	66	67	67
153	69	68	67	67	67	67
156	69	69	67	66	67	67
159	69	69	67	67	67	67
All Readings Through 298 Seconds Vary Only A Few Degrees						
298	119	110	68	69	68	68
322	129	118	69	70	68	68
348	138	127	70	70	68	68
374	147	134	70	70	69	69
412	159	145	70	70	69	68
480	180	162	72	70	70	69

(Continued)

[a]Time starts from initial (test start) time.

Test Number: 12 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
483	180	---	---	---	---	---
527	193	173	73	74	70	69
548	198	178	72	74	70	69
572	204	182	72	74	70	69
590	208	186	72	75	70	70
661	224	198	72	74	70	70
902	266	231	69	74	68	68
1226	308	264	77	79	73	72
1486	335	287	72	73	70	73
1826	363	312	75	77	71	74
2105	383	327	74	81	73	73
2651	413	353	76	78	72	76
3097	523	443	86	78	75	85
3150	557	474	84	79	77	83
3171	570	485	86	79	76	85
3211	593	505	81	80	75	80
3223	600	511	82	79	75	82
3269	626	535	82	89	74	79
3284	635	541	81	99	74	77
3371	657	565	74	97	72	72
3428	658	579	77	100	72	72
[b]3717	635	573	83	90	77	77
3896	606	560	86	233	72	79
3908	611	578	80	192	71	75
3920	615	598	76	163	71	72
3932	617	613	74	144	70	71
4151	542	482	118	· 135	74	76
4163	543	477	115	120	77	74

(Continued)

[a]Time starts from initial (test start) time.
[b]Flame spotted after 3717 seconds.

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Test Number: 12 (Concluded)

Elapsed Time, Seconds	Channels--Temperature, °F					
	00	01	02	03	04	05
4175	542	472	105	103	77	73
4205	542	464	101	110	74	77
4208	539	464	98	108	74	76
4211	535	463	95	105	74	76

[a]Time starts from initial (test start) time.
[b]Flame spotted after 3717 seconds.

Test Number: 13
Initial (Test Start) Time: 04:12:26
Start (Recorder) Time: 04:20:10
High Temperature: 744°F (Channel 00 At 612 Seconds)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time	71	71	71	71	71	71
Start Time[a]	126	122	73	73	72	73
3	129	126	73	73	73	72
24	154	151	73	73	73	73
27	158	155	73	74	73	73
47	183	182	74	75	73	73
53	190	189	74	75	73	73
81	221	223	76	76	76	75
106	246	250	77	77	76	76
135	272	281	77	78	75	75
179	308	324	77	78	76	75
239	363	382	77	80	76	76
278	398	419	77	81	76	75
305	420	444	78	82	76	76
324	436	462	79	82	77	77
375	480	519	78	87	76	76
406	505	555	80	92	76	77
432	515	575	81	94	76	76
480	561	613	82	95	77	77
502	627	628	79	99	76	76
537	682	660	78	100	75	75

(Continued)

[a] Time starts from start (recorder) time.

Test Number: 13 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
571	737	676	78	109	75	75
612	744	672	81	105	77	77
639	715	656	80	99	76	76
692	674	616	81	95	77	76
1142	370	363	75	82	75	74
1148	368	361	75	82	75	74
1165	665	401	79	128	76	78
1172	685	427	79	131	76	77
1177	679	447	79	139	76	77
1183	625	457	78	129	75	76
1189	573	459	77	121	75	76
1195	535	459	77	118	75	75
1201	508	457	76	115	75	75
1207	490	454	75	109	74	74
1213	478	450	75	108	74	74
1219	469	445	75	107	74	74
1225	461	440	75	105	73	74
1231	452	436	76	102	74	75
1237	447	433	76	116	74	75
1243	439	432	76	149	74	76
1248	435	435	76	143	74	75
1254	432	440	76	136	75	75
1260	430	445	76	137	75	75
1266	428	451	76	140	74	75
1272	426	463	77	130	75	75
1277	423	478	78	125	76	75
1283	421	492	78	122	75	75
1289	419	503	77	117	75	75
1292	419	506	77	116	75	75

[a]Time starts from start (recorder) time.

Test Number: 14
Initial (Test Start) Time: Not Recorded
Start (Recorder) Time: 01:09:31
High Temperature: 880°F (Channel 00 At 1999 Seconds)
Notes: Transformer (6 x 6 x 6 inches). Test started with current
limiter on primary side--limiter removed at 1729 seconds.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time	409	491	76	98	75	75
3	408	---	---	---	---	---
Start Time [a]	129	71	54	53	54	53
3	-132	---	---	---	---	---
35	165	81	56	54	55	53
39	167	---	---	---	---	---
110	233	102	60	61	57	54
207	308	131	63	61	60	55
264	347	147	66	64	61	54
[b]330	389	165	67	65	60	55
423	444	191	67	78	65	55
538	508	209	73	67	59	55
602	543	198	58	59	53	53
630	575	234	58	66	54	56
755	626	291	61	77	54	55
813	654	309	57	65	53	53
904	713	332	60	71	54	55
1016	767	362	65	81	55	56
1075	792	377	59	68	52	54
1184	822	431	57	63	52	54

(Continued)

[a]Time starts from start (recorder) time.
[b]Smoke spotted at 330 seconds.

47

Test Number: 14 (Concluded)

Elapsed-Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
1291	766	465	62	65	54	56
1729	514	347	55	55	51	51
1986	447	311	---	---	---	---
c1999	880	309	88	103	53	57
2003	830	309	141	119	54	65
2009	718	308	157	185	53	70
2019	630	307	399	393	58	109
2029	601	306	582	651	57	168
2035	590	305	505	589	57	179
2042	582	304	443	526	56	184
2051	577	304	339	442	57	173
2063	572	303	240	318	55	143
2083	571	302	146	226	53	107
2103	556	302	110	188	52	83
2116	526	301	88	136	52	72
2119	517	301	84	126	51	70
d2122	512	301	81	118	51	67
2128	502	301	74	103	51	64
2135	494	301	70	93	50	61
2138	490	301	67	88	50	59
2253	433	294	54	59	65	52

[a]Time starts from start (recorder) time.
[b]Smoke spotted at 330 seconds.
[c]Flame spotted at 1999 seconds.
[d]Flame out at 2122 seconds.

Test Number: 15
Initial (Test Start) Time: 02:04:05
Start (Recorder) Time: 02:04:05
High Temperature: 857°F (Channel 01 At 238 Seconds)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	54	55	51	51	51	51
51	54	55	51	51	51	50
54	54	55	51	50	51	50
58	55	56	51	51	51	50
61	55	59	51	51	51	51
64	58	65	51	51	51	50
67	72	79	51	51	51	51
71	160	110	51	51	51	51
87	198	202	51	62	52	52
101	196	217	52	56	51	51
104	195	223	52	63	51	---
116	206	261	52	72	51	51
119	230	275	52	80	51	51
122	308	287	52	95	51	51
125	390	313	52	87	51	51
129	456	331	53	84	51	51
132	503	344	52	93	51	51
135	534	362	52	94	51	51
138	550	377	52	94	51	51
141	505	393	52	96	51	51
144	524	424	52	105	51	51

(Continued)

[a] Time starts from initial (test start) time.
[b] No flame; current meter indicated winding open.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	-03	04	05
148	512	487	54	101	51	51
151	498	536	61	106	51	52
154	505	557	65	120	51	55
157	518	582	64	139	51	57
160	530	603	67	145	51	57
163	535	625	71	151	51	60
166	536	648	71	160	51	64
169	532	674	70	178	51	62
172	538	680	69	171	51	61
176	544	676	68	180	51	60
179	546	676	66	184	51	59
182	541	578	65	193	51	58
185	533	680	66	183	51	62
188	522	685	66	177	51	62
191	511	675	65	170	51	61
194	520	655	67	164	51	64
198	512	672	65	169	51	63
201	503	684	64	181	51	62
204	497	695	63	183	51	61
207	497	706	64	179	52	63
210	502	716	64	182	52	61
213	508	---	---	---	---	---
221	532	758	64	178	52	60
224	538	729	67	172	51	61
227	564	782	---	---	---	---
238	621	857	83	183	51	66
[b]242	606	847	79	175	51	65
252	565	809	69	141	51	61

(Continued)

[a]Time starts fr   itial (test start) time.
[b]No flame; c.   nt meter indicated winding open.

Test Number: 15 (Concluded)

Elapsed Time, Seconds	Channels--Temperature, °F					
	00	01	02	03	04	05
256	554	796	68	137	51	60
259	544	784	56	133	51	59
262	535	773	65	126	51	59
265	525	761	63	124	51	58
268	516	759	62	124	51	57

[a] Time starts from initial (test start) time.
[b] No flame; current meter indicated winding open.

51

Test Number: 16
Initial (Test Start) Time: 02:19:16
Start (Recorder) Time: 02:19:29
High Temperature: 784°F (Channel 01 At 159 Seconds)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	51	52	52	52	52	52
3	51	52	52	52	52	52
6	53	56	52	52	52	52
10	62	67	52	52	52	52
Start Time	78	87	52	53	52	52
16	106	165	52	54	52	52
19	139	198	52	60	52	52
[b]22	172	200	52	79	52	52
26	206	204	54	91	52	52
29	236	207	57	107	52	52
32	264	220	57	98	52	52
35	296	248	55	111	52	52
38	320	271	54	126	52	52
41	342	294	56	112	52	52
45	367	322	55	109	52	52
48	388	349	54	115	52	52
51	409	378	54	110	52	52
54	432	421	59	108	52	52
58	451	466	60	97	52	52
61	467	516	61	95	52	52
64	481	552	63	100	52	52

(Continued)

[a] Time starts from initial (test start) time.
[b] Smoke observed at 22 seconds.

Test Number: 16 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
67	498	573	61	109	52	52
70	512	593	60	115	52	52
73	526	606	59	125	52	52
76	540	618	59	145	52	52
79	548	630	62	165	52	53
82	551	645	64	175	52	53
86	554	660	63	183	52	53
89	530	674	61	186	52	53
92	525	687	60	191	52	52
95	529	697	59	203	52	52
98	535	706	58	213	52	53
101	545	712	58	216	52	52
104	564	727	70	224	53	56
107	582	740	77	228	56	65
110	605	752	107	237	60	69
113	627	762	124	239	71	67
116	632	772	124	240	78	67
128	701	773	106	238	71	69
131	697	767	118	238	70	76
[c]135	593	760	141	247	70	86
138	639	754	164	244	70	93
141	686	749	188	238	68	89
152	664	765	778	575	245	376
156	659	778	751	579	229	348
159	654	783	698	617	213	325
162	650	784	650	605	202	300
165	646	781	576	653	181	268
168	643	777	523	682	167	245

(Continued)

[a]Time starts from initial (test start) time.
[b]Smoke observed at 22 seconds.
[c]Flame spotted at 135 seconds.

53

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
171	640	775	481	717	153	227
174	637	775	431	694	141	206
177	634	774	398	672	133	191
180	632	773	375	651	123	179
183	629	773	342	652	115	168
187	627	775	317	640	108	155
190	625	771	290	612	101	143
193	623	765	265	584	95	133
196	621	760	244	565	90	127
199	620	761	230	557	86	120
202	618	758	216	533	84	114
205	616	757	201	515	80	107
208	614	758	189	521	76	101
211	612	760	177	513	74	97
214	611	759	164	494	71	92
217	609	756	153	474	69	88
220	607	749	145	451	68	85
223	606	735	138	427	66	83
[d]232	600	685	119	372	63	75
240	595	650	106	331	61	71

[a]Time starts from initial (test start) time.

[b]Smoke observed at 22 seconds.

[c]Flame spotted at 135 seconds.

[d]Flame out after 232 seconds.

Test Number: 27

Initial (Test Start) Time: 00:44:49

Start (Recorder) Time: 19:43:04

High Temperature: 516°F (Channel 00 At 24 Seconds)

Thermocouple Locations:
- 00: Inside secondary
- 01: 3 inches above primary
- 02: 3 inches above and 3 inches offset from primary
- 03: 3 inches above and 6 inches offset from primary
- 04: 6 inches above transformer
- 05: 6 inches above and 3 inches offset from primary

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time	77	76	75	75	76	76
Start Time[a]	155	75	67	67	68	68
6	276	70	68	68	70	69
12	422	74	69	69	70	70
[b]18	491	81	73	72	71	71
24	516	88	76	73	72	73
30	488	84	78	74	72	72
35	453	82	78	74	71	72
41	418	81	78	73	71	71
47	395	80	77	73	71	72
53	381	78	77	73	70	71
59	370	76	77	74	68	71
78	347	82	82	90	75	76
84	340	79	80	88	75	75
90	335	78	79	85	74	74
96	331	76	78	82	73	73
102	328	75	77	80	73	73
108	325	73	75	78	72	72
114	322	72	74	76	72	72
120	319	71	73	75	72	72

[a]Time starts from start (recorder) time.

[b]Smoke first observed at 18 seconds.

Test Number: 28

Initial (Test Start) Time: 00:38:49

Start (Recorder) Time: 00:38:49

High Temperature: 275°F (Channel 00 At 214 Seconds)

Thermocouple Locations: 00: Inside secondary
                         01: 3 inches above primary
                         02: 3 inches above and 3 inches offset from primary
                         03: 3 inches above and 6 inches offset from primary
                         04: 6 inches above transformer
                         05: 6 inches above and 3 inches offset from primary

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	115	76	76	75	77	76
3	115	76	76	76	77	76
6	115	76	76	75	77	76
9	115	76	76	75	77	76
12	114	76	76	75	77	76
15	114	76	76	75	77	76
18	114	76	76	75	77	76
21	114	76	76	75	77	76
24	114	76	76	75	77	76
27	115	76	76	75	77	76
30	115	76	76	76	77	76
37	119	76	76	76	77	76
40	120	76	76	76	77	76
43	122	76	76	76	77	76
46	125	76	76	76	77	76
49	128	76	76	76	77	76
52	131	76	77	76	77	76
55	133	77	77	76	77	76
58	136	77	77	76	77	76
61	141	77	77	76	77	76
64	146	77	77	76	77	76

(Continued)

[a]Time starts from initial (test start) time.

[b]Flame spotted after 85 seconds.

56

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
67	152	76	---	---	---	---
78	177	78	100	80	80	80
82	182	77	96	79	79	80
b85	186	77	94	79	79	80
87	190	77	91	79	79	79
90	193	77	89	78	79	79
93	196	77	88	78	79	79
96	200	77	86	78	78	78
99	203	77	85	77	78	78
102	207	77	84	77	78	78
105	210	76	83	77	78	78
108	214	77	82	77	78	77
111	218	77	81	77	78	77
114	221	76	81	77	78	77
117	224	76	80	77	78	77
120	226	76	79	77	78	77
123	229	76	79	77	78	77
126	231	76	78	77	78	77
129	234	76	78	76	78	77
132	237	76	78	76	77	77
135	239	76	78	76	77	77
138	241	76	77	76	77	77
140	243	76	77	76	77	77
143	244	76	77	76	77	77
146	247	76	77	76	77	77
149	249	76	77	76	77	77
152	251	76	77	76	77	77
155	253	76	77	76	77	77

(Continued)

[a] Time starts from initial (test start) time.
[b] Flame spotted after 85 seconds.

Test Number: 28 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
166	259	76	77	76	77	77
176	264	76	77	76	77	77
193	270	76	77	76	77	76
195	270	---	---	---	---	---
214	275	76	77	76	77	77

[a]Time starts from initial (test start) time.

[b]Flame spotted after 85 seconds.

Test Number: 29

Initial (Test Start) Time: 00:53:56

Start (Recorder) Time: 00:54:51

High Temperature: 598°F (Channel 00 At 271 And 274 Seconds)

Thermocouple Locations:
- 00: Inside secondary
- 01: 3 inches above primary
- 02: 3 inches above and 3 inches offset from primary
- 03: 3 inches above and 6 inches offset from primary
- 04: 6 inches above transformer
- 05: 6 inches above and 3 inches offset from primary

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	75	75	75	75	76	76
3	75	75	75	75	77	76
6	75	75	75	75	76	76
9	75	75	75	75	76	76
12	75	75	75	75	76	75
15	75	75	75	75	76	76
18	75	75	75	75	76	76
21	75	75	75	75	76	76
24	76	75	75	75	76	76
27	76	75	75	75	76	76
36	80	75	75	75	76	76
39	83	75	75	75	76	76
42	86	75	75	75	76	76
45	90	75	75	75	76	76
48	95	75	75	75	76	76
51	99	75	75	75	76	76
54	105	76	76	75	76	76
57	110	75	76	75	76	76
60	116	75	76	75	76	76
63	122	75	76	75	76	76
66	129	75	76	75	76	76

(Continued)

[a] Time starts from initial (test start) time.

59

Test Number: 29 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
69	136	75	77	75	76	76
72	144	76	79	76	76	76
Start Time	153	76	84	78	76	76
130	160	78	89	80	76	77
133	169	80	94	81	76	78
136	180	84	98	83	77	78
139	193	84	98	84	77	78
142	204	84	99	84	77	78
145	214	82	98	85	77	78
148	226	84	99	86	77	78
151	236	85	100	86	77	79
154	245	85	99	86	77	79
157	255	83	98	87	77	78
160	265	82	97	86	77	78
163	274	81	95	85	77	78
166	291	82	94	84	77	78
169	303	81	92	84	77	78
172	309	80	91	83	77	78
175	316	80	90	83	77	78
178	321	80	89	83	77	78
181	327	79	89	83	77	78
184	336	78	87	82	77	77
187	345	78	86	81	77	77
190	352	77	85	81	77	77
210	414	77	81	79	77	77
212	422	77	80	78	77	77
215	428	77	80	78	77	77
218	432	76	80	78	77	77
221	441	76	80	78	77	77

(Continued)

[a]Time starts from initial (test start) time.

Test Number: 29 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
224	450	77	80	78	77	77
227	462	76	80	78	77	76
230	475	76	79	78	77	77
b233	487	76	79	78	77	77
256	576	155	409	189	109	197
259	584	157	439	202	110	201
262	590	162	453	204	112	199
265	594	151	436	201	111	190
268	597	138	402	195	110	182
271	598	129	384	186	109	176
274	598	121	349	175	107	165
277	597	110	307	161	105	153
280	596	104	275	151	103	145
283	594	99	248	141	101	137
285	592	96	223	133	99	131
288	591	92	207	127	98	126
291	587	90	190	121	97	120
294	583	88	175	116	96	116
297	579	86	161	110	94	112
300	575	85	150	107	92	108
303	571	83	140	104	91	105
306	566	82	131	100	90	102
309	561	81	125	97	89	100
312	556	81	119	96	88	97
314	551	81	114	94	87	95
318	545	80	109	92	86	93
c321	539	80	105	90	86	92

(Continued)

aTime starts from initial (test start) time.
bFlame spotted after 233 seconds.
cFlame out after 321 seconds.

61

Test Number: 29 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
323	533	80	101	88	85	90
327	526	80	98	87	84	89
329	519	79	95	86	84	88
332	512	79	93	35	83	87
335	506	79	91	8	33	86
338	502	79	90	83	83	85

[a]Time starts from initial (test start) time.

[b]Flame spotted after 233 seconds.

[c]Flame out after 321 seconds.

Test Number: 30

Initial (Test Start) Time: 20:39:49

Start (Recorder) Time: 20:39:49

High Temperature: 775°F (Channel 00 At 187, 190, And 193 Seconds)

Thermocouple Locations:
  00: Inside secondary
  01: 3 inches above primary
  02: 3 inches above and 3 inches offset from primary
  03: 3 inches above and 6 inches offset from primary
  04: At SAFECAN nozzle
  05: 6 inches above and 3 inches offset from primary

Notes: SAFECAN nozzle placed 2 1/2 inches above transformer. Heat detecting solder did not melt.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time[a]	141	71	71	71	71	71
3	143	71	71	71	71	71
5	144	71	71	71	71	71
9	148	71	71	71	71	72
12	175	71	71	71	71	71
15	196	72	71	71	71	71
18	201	72	71	71	71	71
21	202	72	71	71	71	71
24	204	72	71	71	71	72
27	207	72	72	72	71	72
30	212	73	72	72	71	72
33	216	73	72	72	71	72
35	232	73	72	72	72	72
38	246	73	72	72	71	72
41	257	73	72	72	72	72
44	267	73	72	72	72	72
47	285	74	72	72	72	72
50	297	74	72	72	72	72
53	304	79	74	73	72	72

(Continued)

[a] Time starts from initial (test start) time.
[b] Flame spotted after 56 seconds.

Test Number: 30 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
b_{56}	321	83	80	74	72	72
62	376	97	87	79	73	73
65	403	98	88	81	73	73
69	433	---	---	---	---	---
79	515	435	436	231	144	225
83	541	342	409	213	138	203
86	563	376	374	195	131	189
88	584	330	341	182	123	178
92	605	273	310	170	116	163
95	622	247	281	163	111	153
97	637	261	261	157	107	145
100	649	243	243	149	106	138
103	656	232	228	144	107	134
106	670	226	214	139	104	126
109	679	215	201	133	105	122
112	688	191	186	128	101	117
115	697	178	178	122	99	112
118	703	171	171	117	97	109
121	710	164	164	116	97	106
124	714	155	158	112	96	108
127	718	164	168	118	119	106
129	721	156	160	117	116	103
132	724	159	151	116	111	100
135	729	147	147	111	106	97
138	732	147	141	109	103	95
141	734	146	135	104	98	93
144	735	153	131	102	95	91
154	742	120	118	94	90	86

(Continued)

[a]Time starts from initial (test start) time.
[b]Flame spotted after 55 seconds.

64

Test Number: 30 (Concluded)

Elapsed Time, Seconds	Channels--Temperature. °F					
	00	01	02	03	04	05
157	746	125	115	92	83	85
^{c}187	775	109	96	81	81	79
190	775	107	96	81	81	79
193	775	106	95	---	---	---

[a]Time starts from initial (test start) time.

[b]Flame spotted after 56 seconds.

[c]Flame out after 187 seconds.

65

Test Number: 32

Initial (Test Start) Time: Not Available

Start (Recorder) Time: Not Available

High Temperature: 227°F (Channel 00 At 234 Seconds)

Thermocouple Locations: 00: Inside secondary
01: 3 inches above primary
02: 3 inches above and 3 inches offset from primary
03: 3 inches above and 6 inches offset from primary
04: At SAFECAN nozzle
05: 6 inches above and 3 inches offset from primary

Notes: SAFECAN fusible link 2 1/2 inches above primary windings. Upper and lower cabinet blowers on. Transformer flamed for about 30 seconds. Fusible link reached 113°F--but did not melt.

Elapsed Time, Seconds	Channels--Temperature, °F					
	00	01	02	03	04	05
Initial Time[a]	54	55	55	55	55	55
3	54	55	55	55	55	55
5	54	55	55	55	55	55
9-18	54	55	55	55	55	55
21	54	55	55	55	56	55
24	55	55	55	55	56	55
27	56	55	55	55	56	55
30	57	55	55	56	56	55
40	63	55	55	55	57	55
43	65	55	56	56	58	55
52	79	56	56	56	58	55
54	84	56	56	56	59	56
57	90	56	56	57	59	56
60	95	56	56	57	59	56
63	99	56	56	57	59	56
66	107	57	56	57	60	56
69	113	57	56	57	60	56
[b]72	116	57	57	58	60	56

(Continued)

[a]Time starts from initial (test start) time.
[b]Small flame spotted at 72 and 94 seconds.

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Test Number: 32 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
75	124	57	56	58	61	---
91	138	59	70	64	113	61
b94	141	58	68	63	103	61
97	143	58	66	63	96	60
100	145	58	65	62	89	60
103	146	58	64	62	84	59
106	150	58	63	62	80	59
109	153	58	62	61	77	59
112	156	58	62	61	74	59
115	160	58	61	61	71	59
118	163	58	61	61	70	58
121	167	57	60	61	68	58
124	170	58	60	60	67	58
127	173	57	59	60	66	57
130	176	57	59	60	65	57
153	198	57	58	59	61	57
155	200	---	---	---	---	---
234	227	56	57	56	59	55

[a]Time starts from initial (test start) time.
[b]Small flame spotted at 72 and 94 seconds.

Test Number: 34

Initial (Test Start) Time: 01:02:07

Start (Recorder) Time: 01:07:04

High Temperature: 402°F (Channel 02 At 81 Seconds)

Thermocouple Locations: 00: Inside secondary
01: 3 inches above primary
02: 3 inches above and 3 inches offset from primary
03: 3 inches above and 6 inches offset from primary
04: At SAFECAN nozzle
05: 6 inches above and 3 inches offset from primary

Notes: SAFECAN fusible link 2 inches above primary windings--fusible link did not melt.

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
Initial Time	65	62	63	63	63	62
Start Time[a]	65	62	63	63	63	62
3	65	62	63	63	64	63
6	64	62	63	63	63	63
9	64	62	63	63	63	63
12	65	62	63	63	64	63
15	65	62	63	63	64	63
18	65	62	63	63	64	63
21	65	62	63	63	64	62
24	64	62	63	63	64	63
27	65	62	63	63	64	62
30	65	62	63	63	64	62
33	65	62	63	63	64	62
[b]36	65	62	63	63	64	63
39	65	62	63	63	64	63
42	66	63	63	63	64	63
45	67	---	---	---	---	---
48	69	63	64	63	64	63
51	71	63	64	63	65	63

(Continued)

[a]Time starts from start (recorder) time.
[b]Smoke spotted at 36 seconds.

Test Number: 34 (Continued)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
54	74	63	64	64	65	63
57	77	64	65	64	66	63
60	80	65	66	64	66	64
63	84	66	70	66	73	64
66	89	69	74	67	74	64
c69	93	69	77	68	72	65
81	113	350	402	242	245	143
84	117	280	367	220	242	134
88	123	216	325	195	229	125
90	127	182	299	179	217	116
93	132	153	272	164	205	112
97	138	132	249	151	193	104
99	143	119	234	143	189	99
102	148	109	219	136	187	95
105	152	98	203	129	180	91
108	155	95	194	124	177	89
111	161	89	182	119	171	85
114	165	88	174	115	167	83
117	170	85	165	'11	164	81
120	173	82	156	08	158	79
123	176	79	148	104	154	78
126	180	78	142	102	148	76
129	183	77	134	98	144	75
132	186	76	128	96	140	74
135	189	74	124	94	136	73
138	191	71	117	91	130	72
141	194	70	111	88	125	71
144	196	69	106	86	120	70

(Continued)

[a]Time starts from start (recorder) time.
[b]Smoke spotted after 36 seconds.
[c]Flame spotted at 69 seconds.

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Test Number: 34 (Concluded)

Elapsed Time, Seconds	Channels--Temperature,°F					
	00	01	02	03	04	05
147	198	68	103	84	117	69
150	200	67	99	82	112	69
152	202	67	95	80	106	68
155	204	66	91	78	100	68
158	205	66	88	77	97	67
161	207	66	85	75	92	67
164	208	65	83	74	89	67

[a]Time starts from start (recorder) time.
[b]Smoke spotted after 36 seconds.
[c]Flame spotted at 69 seconds.

ALARM RECEIVER DESIGN

DESIGN OBJECTIVE AND DESCRIPTION

The alarm receiver must detect a smoke alarm signal in the presence of background computer room noise. The maximum expected noise level is approximately 65 dB throughout the audio spectrum 100 Hz - 20 kHz. At lower frequencies, the noise level can be expected to be much higher. The input signal is to be interfaced to the alarm receiver by way of a low-cost medium-performance microphone. The input signal is amplified to a level that can be processed by the receiver. After being amplified, the input signal may be limited to a predetermined peak to peak value so that the following sections of the receiver are not overdriven to the point of saturation. This condition must be avoided if possible since it will cause unnecessary distortion in the processed input signal.

At this point, two filters are introduced: one is for filtering out a semibroad portion of the background noise with a center frequency of 1 kHz and a bandwidth of 1 kHz; the second filter is for detecting the smoke alarm signal and its center frequency should be the statistical average of the smoke detector alarm signal. At this time, this frequency is approximately 3.25 kHz and should be adjustable. The bandwidth is to be 350 Hz to account for any variations in the installed smoke detector alarms.

The gains of the two filters have not been specified and should be selected for three conditions. The first and the most obvious condition is the gain of the two filters must be high enough to obtain the desired sensitivity to an incoming input signal. The gain of the two filters must not be so high as to cause any unnecessary distortion. The third, and probably the most important condition for determining the filter gain is that the gain of the noise filter should not be too much greater than the alarm filter, or any valid smoke detector alarm signal may not be detected. The gain of the noise filter should be a slightly higher than the alarm filter. The suggested gain settings should be set at a point between 2 and 4.5. The filter gain settings are somewhat dependent on the desired sensitivity. The higher the gain, the higher the sensitivity of the receiver detecting a valid alarm signal. Increasing the gain of the alarm filter to a high level can have some undesirable effects; such as causing false . rms, which must be entirely avoided.

Once the input signal has been filtered, the output of the two filters
are negatively rectified by separate circuits. Each rectified signal is then
converted to a dc level. Therefore, the output from the alarm filter has been
converted to a dc level and so has the output from the noise filter. These
two dc levels are then subtracted from each other,

        (Noise filter dc level)
      - (Alarm filter dc level)
        Output from subtractor

The output from the subtractor is then applied to a Schmitt trigger with a
variable trigger level. The Schmitt trigger output will indicate whether or
not the smoke detector alarm has gone off. Normally, the trigger output is at
+11 volts. If an alarm signal is occurring, the output of alarm filter inte-
grator will begin to increase. Eventually the alarm filter integrator output
will become greater than that of the noise filter integrator. The output of
the subtractor will become negative, thus causing the Schmitt trigger to
actuate with its output level now at approximately -10 volts dc, indicating a
possible valid alarm.

Basically the idea underlying what has been discussed so far is this: It
was stated earlier that the noise level is approximately maintained at a
constant value in the audio spectrum from 100 Hz to 20 kHz. Taking this fact
as a given, the noise level of 3.25 kHz is approximately equal to the noise
level at 1.0 kHz. If the magnitude of the noise level at both 3.25 kHz and
1.0 kHz can be removed, then all that remains is a very small amount of base
line noise. Under no alarm conditions just the background noise exists. It
is the purpose of the subtractor to remove a good deal of the noise that is
contained in the two filters. The integrators convert the output of the two
filters to a dc level that can be subtracted. In this way, when a valid alarm
is detected, the noise content will be removed allowing the Schmitt trigger to
actuate only by a valid alarm signal. It must be noted that the background
noise cannot be entirely removed.

To guard against false alarms and random 3.25 kHz noise spikes, two
sections of the discriminator have been designed. To guard against 3.25 kHz
noise spikes that may cause a total system reset or a false alarm, the

integrators have been made sluggish. The noise filter integrator is more sluggish than the alarm filter integrator since the alarm filter integrator must be more responsive to signal changes than the noise filter integrator. To summarize, the integrators have been made sluggish to dampen out any noise spikes. The other section that guards against false alarms is a delay circuit. The smoke detector alarm must persist for at least 15 seconds before it will be considered a valid signal. Fifteen seconds after an alarm has been detected, the output of the entire receiver will respond with a Logic 1 voltage level.
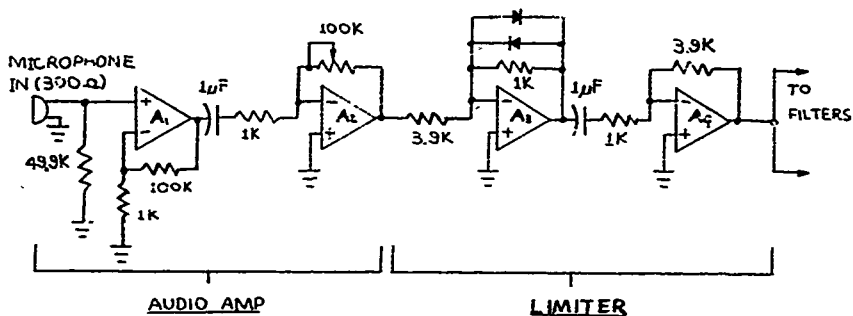
The audio amplifier's gain can be adjusted from a value of a little less than 100 to a maximum of 10,000.
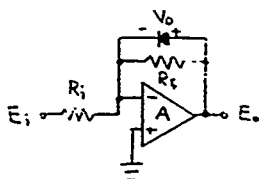
Simple Clamper

When Ei becomes negative, Eo will become positive and the diode will come on at a specific input voltage, dependent on the input and feedback resistors.

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When the diode comes on, the voltage across the feedback resistor will be clamped to the forward biased diode voltage drop. This means that the current through the feedback resistor will be If = Vo/Rf just before the diode breakpoint. Assuming the op-amp is ideal, then the inverting input is a virtual ground and the op-amp will draw no current.

$$I_{Ri} = I_{Rf} = \frac{Vo}{Rf}$$

then
$$Ei = (V_D)\left(\frac{Ri}{Rf}\right)$$

and in this case Ei will be negative and Eo will be limited at

$$E_0 = - (V_D) \left(\frac{Ri}{Rf}\right)\left(- \frac{Rf}{Ri}\right)$$

or $E_0 = V_D$, one diode drop. To achieve the limit function, the output of the clamper must be amplified by the inverse ratio of Rf/Ri, therefore, Ri/Rf.

The final circuit is shown below. The extra diode is added so that both positive and negative limiting occurs.
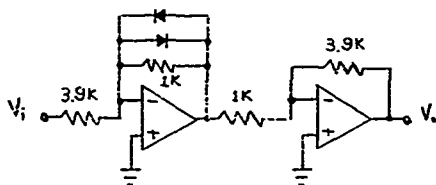
Assuming the diode drop equals 0.7 volts. Limiting occurs at $-2.73\ V < V_0 < + 2.73\ V$. Knowing the output limits will also give the needed information on microphone input that will cause limiting.

With the audio amplifier gain set at Av, the microphone input that will cause limiting is:

(Av) Audio Amplifier Gain	Microphone input that will cause limiting (peak)
100	±27.3 mV
10,000	±273 μV

Alarm filter design
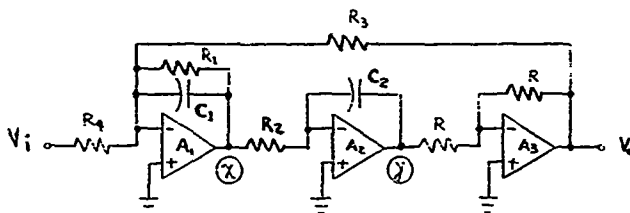
Resonator Filter (Tow-Thomas)

Second order filter General Transfer Functions:

$$H(s)_{BP} = \frac{Ho \left(\frac{\omega_0}{Q}\right) s}{s^2 + \left(\frac{\omega_0}{Q}\right) s + \omega_0^2} \quad ; \text{ Band pass 2nd order}$$

$$H(s)_{LP} = \frac{Ho \cdot \omega_0^2}{s^2 + \left(\frac{\omega_0}{Q}\right) s + \omega_0^2} \quad ; \text{ Low pass 2nd order}$$

$$H(s)_{HP} = \frac{H_0 \cdot s^2}{s^2 + \left(\frac{\omega_0}{Q}\right) s + \omega_0^2} \quad ; \text{ High pass 2nd order}$$

$$H(s) = \frac{V_0(s)}{Vi(s)} \; ; \qquad Z_{EQ} = \frac{R}{1 + sRC} = \frac{\dfrac{1}{C}}{s + \dfrac{1}{RC}}$$

At pt. X on the filter.

By superposition and Thevenins Theorem

$$V_x(s) = -\frac{Vi(s)\, R_3}{R_3 + R_4} \cdot \frac{\left(\dfrac{\dfrac{1}{C_1}}{s + \dfrac{1}{R_1 C_1}}\right)}{\left(\dfrac{R_3 R_4}{R_3 + R_4}\right)} - \frac{V_0(s) R_4}{(R_4 + R_3)} \cdot \frac{\left(\dfrac{\dfrac{1}{C_1}}{s + \dfrac{1}{R_1 C_1}}\right)}{\left(\dfrac{R_3 R_4}{R_3 + R_4}\right)}$$

$$= -\frac{\dfrac{1}{R_4 C_1}}{s + \dfrac{1}{R_1 C_1}} \, Vi(S) - \frac{\dfrac{1}{R_3 C_1}}{s + \dfrac{1}{R_1 C_1}} \, V_0(s) \qquad (1)$$

$$V_0(s) = -Vy(s) = \frac{1}{sR_2 C_2} \, Vx(s) \qquad (2)$$

$$Vx(s) = sR_2 C_2 \, V_0(s) \qquad (2)'$$

Find $H(S) = \dfrac{V_0(s)}{Vi(s)}$ by substituting Equation (2)' into Equation (1)

$$sR_2 C_2 V_0(s) = -\frac{\dfrac{1}{R_4 C_1}}{s + \dfrac{1}{R_1 C_1}} Vi(s) - \frac{\dfrac{1}{R_3 C_1}}{s + \dfrac{1}{R_1 C_1}} V_0(s) \tag{1}$$

Collecting terms:

$$V_0(s)\left(sR_2 C_2 + \frac{\dfrac{1}{R_3 C_1}}{s + \dfrac{1}{R_1 C_1}}\right) = -\frac{\dfrac{1}{R_4 C_1}}{s + \dfrac{1}{R_1 C_1}} Vi(s)$$

$$H(s) = \frac{V_0(s)}{Vi(s)} = -\left(\frac{\dfrac{1}{R_4 C_1}}{s + \dfrac{1}{R_1 C_1}}\right) \cdot \frac{s + \dfrac{1}{R_1 C_1}}{s^2 (R_2 C_2) + s\left(\dfrac{R_2 C_2}{R_1 C_1}\right) + \dfrac{1}{R_3 C_1}}$$

$$= -\frac{\dfrac{1}{R_4 C_1}}{s^2 (R_2 C_2) + s\left(\dfrac{R_2 C_2}{R_1 C_1}\right) + \dfrac{1}{R_3 C_1}} \cdot \frac{\dfrac{1}{R_2 C_1}}{\dfrac{1}{R_2 C_2}}$$

$$= -\frac{\dfrac{1}{R_4 R_2 C_1 C_2}}{s^2 + s\left(\dfrac{1}{R_1 C_1}\right) + \dfrac{1}{R_2 R_3 C_1 C_2}} \quad ; \text{ Low pass transfer function} \tag{3}$$

From equation (2): $V_0(s) = \dfrac{Vx(s)}{sR_2 C_2}$ substitute Equation (2) into Equation (3) to obtain the band-pass transfer function

$$H_{BP}(s) = \frac{V_x(s)}{V_1(s)} = -\frac{\left(\dfrac{1}{R_1 C_1}\right)s}{s^2 + s\left(\dfrac{1}{R_1 C_1}\right) + \dfrac{1}{R_2 R_3 C_1 C_2}} \quad ; \text{ Band pass transfer function} \tag{3}$$

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Compare the transfer function above to the generalized Band-pass transfer function.

$$H_{BP}(s) = \frac{H_v \left(\frac{\omega_0}{Q}\right) s}{s^2 + \left(\frac{\omega_0}{Q}\right) s + \omega_0^2} \quad ; \text{ Band-pass 2nd order}$$

$$H_{BP}(s) = - \frac{\left(\frac{1}{R_4 C_1}\right) s}{s^2 + s \left(\frac{1}{R_1 C_1}\right) - \frac{1}{R_2 R_3 C_1 C_2}} \tag{3}$$

where:

$$H_v \left(\frac{\omega_0}{Q}\right) = - \frac{1}{R_4 C_1}$$

$$\frac{\omega_0}{Q} = \frac{1}{R_1 C_1}$$

$$\omega_0^2 = \frac{1}{R_2 R_3 C_1 C_2}$$

Resonator Filter 2nd Order Band-pass

$$H_v = - \frac{R_1}{R_4} \quad ; \text{ this is the gain of the filter.}$$

$$\omega_0 = \frac{1}{\sqrt{R_2 R_3 C_1 C_2}} \quad ; \text{ center frequency}$$

$$Q = R_1 \sqrt{\frac{C_1}{R_2 R_3 C_2}} \quad ; \text{ Quality factor} = \frac{\omega_0}{BW}$$

To yield a noninverting filter, amplifiers A_2 and A_3 are interchanged as shown below.

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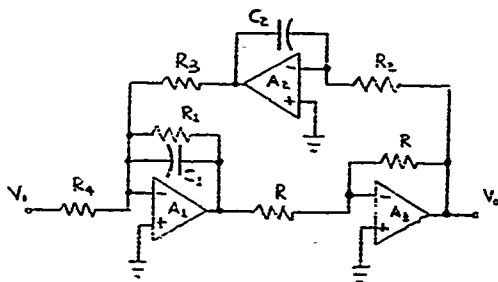
Noninverting Resonator Band-pass Filter

To develop a design procedure, let $R = R_2$, $C_1 = C_2$

Recall

$$H_{BP}(s) = \frac{H_0\left(\dfrac{\omega_0}{Q}\right) s}{s^2 + \left(\dfrac{\omega_0}{Q}\right) s + \omega_0{}^2}$$

Also let $\rho = \dfrac{H_0}{Q}$ and $\beta = \dfrac{1}{Q}$

Choose C_1 near $10/f_0$ μF

then

$$R_4 = \frac{1}{\rho \omega_0 C_1} \ , \ R_2 = \frac{1}{\beta \omega_0 C_1} = \frac{\rho}{\beta} \, R_4$$

$$R_3 = \frac{1}{\omega_0^2 C_1^2 R}$$

where R is entirely arbitrary and a reasonable value could be $R = R_3 = \dfrac{1}{\omega_0 C_1}$

With these design equations, the three filter parameters H_0, ω_0, and Q now become

$$H_0 = \frac{R_1}{R_4}$$

$$\omega_0 = \frac{1}{\sqrt{RR_3}} \ ;$$

R_3 may be used to adjust the center frequency ω_0.

$$Q = \frac{R_1}{\sqrt{R \, R_3}}$$

Before actually calculating the component values for the filter, a short digression will be made pertaining to the resonator filter. The resonator filter is basically an RC oscillator with degenerative feedback. The filter is also known as a biquadratic filter but the biquadratic name actually refers to a type of transfer function, so the name resonator has a direct reference to this filter.

The resonator filter has its roots from the analog computer quadrature oscillator shown below.

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DEGENERATIVE FEEDBACK
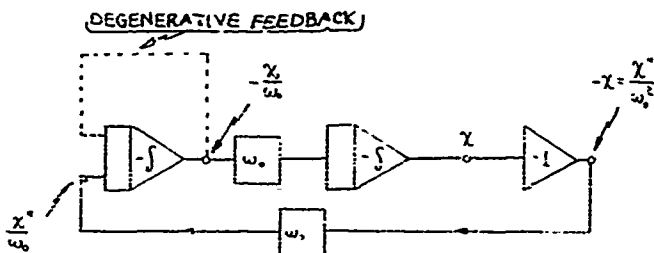
Without the degenerative feedback, the block diagram above will solve the differential equation ... $x''(t) + \omega_0^2 \cdot x(t) = 0$ which has the solution ... $x(t) = A \sin \omega_0 t$. When the block diagram is implemented with op-amps, the R_1 resistor serves as the degenerative feedback path while the input signal is applied to the filter through R_4. The analysis of the filter has been done earlier. What makes the filter so attractive is the simplicity of design while also having an overall low sensitivity and the ability to achieve high values of Q ($= \omega_0/BW$). The resonator filter is one of the most versatile second-order filter designs available and is highly valuable as a building block when designing higher order filters as will be done when the alarm filter design is completed. This will now be introduced.

The type of filter block that is used to achieve the higher order filter is called a Primary Resonator Block filter or just PRB filter. Its advantage over other filter block realizations is that it does not require the second order filter blocks that are ultimately used to construct the filter to have infinite Q. Its disadvantage is that the design equations are somewhat complicated and tedious to calculate. A block diagram of the PRB filter is shown below.
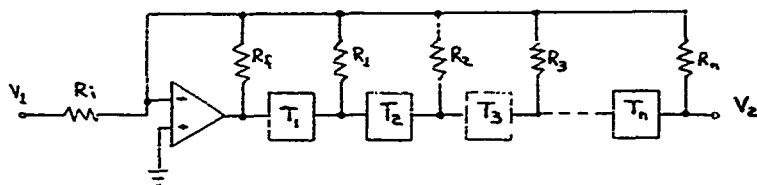
PRB FILTER

$Ri (i = 1, 2, 3, \ldots, n)$

$$\frac{V_2(s)}{V_1(s)} = \frac{-a_0 T_1(s) T_2(s) \ldots T_n(s)}{1 + a_1 T_1(s) + a_2 T_1(s) T_2(s) + \ldots + a_n T_1(s) T_2(s) \ldots T_n(s)} \quad 1)$$

Each box above represents a second-order transfer function having a zero-output impedance. Consider an inverting nth order normalized low-pass filter (BW = 1 rad/s)

$$H_{LP}(s) = \frac{V_2(s)}{V_1(s)} = \frac{-Hb_0}{b_n s^n + b_{n-1} s^{n-1} + \ldots + b_1 s + b_0} = \frac{-Hb_0}{\rho(s)} \quad (2)$$

Using the normalized low-pass to band-pass transformation,

$$s = Q \frac{\rho^2 + 1}{\rho} \quad (3)$$

where ρ is the resulting transformed complex frequency variable.

$$Q(\text{quality}) = \frac{\omega 0}{BW}$$

$$s = Q \frac{\rho^2 + 1}{\rho} \quad (4)$$

center frequency $\omega_0 = 1$,

$$BW = \frac{1}{Q}$$

Substitute (4) into (2) and replace ρ with s to obtain the normalized band-pass transfer function.

$$H_{BP}(s) = H_{LP}\left(Q\frac{s^2 + 1}{s}\right) = \frac{V_2(s)}{V_1(s)} = \frac{-H_0 b_0 s^n/Q^n}{D_1(s)} \tag{5}$$

$$D_1(s) = \sum_{i=0}^{n} \frac{b_{n-1} s^i (s^2 + 1)^{n-i}}{Q^i} \tag{6}$$

To simplify the design, all filters are assumed to be identical and, in fact they are identical in this design. The filter blocks are of the following form:

$$Ti(s) = \frac{H_0(s/Q\rho)}{s^2 + \left(\frac{1}{Q\rho}\right)s + 1} \tag{7}$$

$i = 1,2,3, \ldots, n$

The transfer function with the filter blocks like those described in Equation (7) now becomes

$$\frac{V_2(s)}{V_1(s)} = \frac{-a_0 H_0^n s^n/Q\rho^n}{D_2(s)} \tag{8}$$

where

$$D_2(s) = \left(s^2 + \frac{1}{Q\rho} s + 1\right)^n + \sum_{i=1}^{n} \frac{ai H_0^i s^i [s^2 + (1/Q\rho)s + 1]^{n-i}}{\mathcal{D}} \tag{9}$$

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Apply the binominal theorem to $D_2(s)$:

$$D_2(s) = \sum_{i=0}^{n} (i^n)(s^2+1)^{n-i}(s/Q_0)^i + \sum_{i=0}^{n}\sum_{j=0}^{n-i} a_j H_0^{\ i}(j^{n-i})(s^2+1)^{n-i-j}(s/Q_p)^{i+j}$$

(10)

NOTE: $\binom{a}{b} = \dfrac{a!}{(a-b)!\,b!}$

The feedback circuit shown on page B-13 is obtained by equating Equations (8) and (10) with (5) and (6) which gives the following result:

$$\frac{a_0 H_0^{\ n}}{Q_0^{\ n}} = \frac{Hb_0}{Q^n}$$

(11)

and

$$\binom{n}{k}\frac{1}{Q_p^{\ k}} + \sum_{i=1}^{k} a_i H_0^{\ i}\binom{n-1}{k-i}\frac{1}{Q_p^{\ k}} = \frac{b_{n-k}}{Q_k}\ ;\ k = 1,2,3,\ \ldots,\ n$$

(12)

To solve Equations (11) and (12) make the following assignments:

$$H_0 = \frac{1}{C} \qquad Q_p = \frac{Q}{C}$$

(13)

C is aribtrary and is chosen so as not to make a_i negative.
Substituting Equation (13) into Equation (12) and (11) results in

$$a_0 = Hb_0$$

and

$$a_1 = b_{n-1} - c^n$$

$$a_k = b_{n-k} - \binom{n}{k}C^k - \sum_{i=1}^{k-1}\binom{n-1}{k-i} a_i C^{k-i}\ ;\ k = 2,\ 3,\ \ldots,\ n$$

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Therefore, given (choosing) C, a_k may be solved for.

NOTE: If $0 < C < \dfrac{b_{n-1}}{n}$ then $a_1 > 0$.

If C can be chosen such that one of the a_i is zero, then the corresponding feedback resistor $(a_i \implies R_i)$ in the PRB realization will be infinite, thus, eliminating a component. A most desirable effect of the PRB realization is the gain of the entire filter is set by the input resistor which obeys the equation

$$R_0 = \frac{Rf}{H_{b_0}}; \quad H_0 = gain$$

Each filter block (T_n) is a second-order noninverting filter. If C is selected as follows:

$$C = \frac{b_{n-1}}{n}$$

then

$$Q = \frac{b_{n-1}}{n} \frac{Q_\rho}{}$$

which gives the smallest Q_ρ for a specified Q.

To design the filter, the b_n's must be found first. They correspond to the normalized denominator coefficients of the form

$$\frac{V_2(s)}{V_1(s)} = \frac{1}{s^n + b_{n-1} s^{n-1} + \ldots + b_2 s^2 + b_1 s + b_0}$$

They may be denominator coefficients of maximally flat (Butterworth) functions or denominator coefficients of equal-ripple (Chebychev) functions, both of the form shown above and repeated below for convenience.

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$$\frac{Y_2(s)}{V_1(s)} = \frac{1}{s^n + b_{n-1} s^{n-1} + \ldots + b_2 s^2 + b_1 s + b_0}$$

With a pass-band of 0 to 1 rad/sec. Refer to Tables B-1 through B-3 for the required data.

1/2 dB Chebychev Bandpass Filter

From Table B-1, with n = 4:

$$\frac{V_2(s)}{V_1(s)} = \frac{1}{s^4 + 1.157386 s^3 + 1.716866 s^2 + 1.025455 s + 0.379051}$$

$b_0 = 0.379051$

$b_1 = 1.025455$

$b_2 = 1.716866$

$b_3 = 1.1197386$

The gain is set by the input resistor $R_0 = \dfrac{R_f}{H b_0}$

If $\qquad C = \dfrac{b_{n-1}}{n} = \dfrac{b_3}{4} = \dfrac{1.1197386}{4} = 0.2799347$

then $\qquad Q_p = \dfrac{q_n}{b_{n-1}} = \dfrac{(9.514)(4)}{1.1197386} = 33.98650$

$H_u = \dfrac{1}{C} = 3.572261$

$\omega_p = 2\pi f = 2\pi (3.33 \text{ kHz}) = 20.9230 \text{ krad/s}$

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TABLE B-1. DENOMINATOR COEFFICIENTS OF EQUAL-RIPPLE MAGNITUDE (CHEBYCHEV) FUNCTIONS OF THE FORM $a_0 + a_1 s + a_2 s^2 + \ldots + a_{n-1} s^{n-1} + s^n$ WITH PASSBAND 0 TO 1 rad/s.

n	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
						1/2-dB ripple				
2	1.516203	1.425625								
3	0.715694	1.534895	1.252913							
4	0.379051	1.025455	1.716866	1.197386						
5	0.178923	0.752518	1.309575	1.937367	1.172491					
6	0.094763	0.432367	1.171861	1.589763	2.171845	1.159176				
7	0.044731	0.282072	0.755651	1.647903	1.869408	2.412651	1.151218			
8	0.023691	0.152544	0.573560	1.148589	2.184015	2.149217	2.656750	1.146080		
9	0.011183	0.094120	0.340819	0.983620	1.611388	2.781499	2.429330	2.902734	1.142571	
10	0.005923	0.049285	0.237269	0.626969	1.527431	2.144237	3.440927	2.709741	3.149876	1.140066
						1-dB ripple				
2	1.102510	1.097734								
3	0.491307	1.238409	0.988341							
4	0.275628	0.742619	1.453925	0.952811						
5	0.122827	0.580534	0.974396	1.688816	0.936820					
6	0.068907	0.307081	0.939346	1.202140	1.930825	0.928251				
7	0.030707	0.213671	0.548620	1.357545	1.428794	2.176078	0.923123			
8	0.017227	0.107345	0.447826	0.846824	1.836902	1.655156	2.423026	0.919811		
9	0.007677	0.070605	0.244186	0.786311	1.201607	2.378119	1.881480	2.670947	0.917548	
10	0.004307	0.034497	0.182451	0.455389	1.244491	1.612986	2.981509	2.107852	2.919466	0.915932

TABLE B-2. DENOMINATOR COEFFICIENTS OF MAXIMALLY FLAT MAGNITUDE (BUTTERWORTH) FUNCTIONS OF THE FORM $s^n + a_1 s^{n-1} + a_2 s^{n-2} + \ldots + a_2 s^2 + a_1 s + 1$ WITH PASSBAND 0 to 1 rad/s

n	a_1	a_2	a_3	a_4	a_5
2	1.414214				
3	2.000000				
4	2.613126	3.414214			
5	3.236068	5.236068			
6	3.863703	7.464102	9.141620		
7	4.493959	10.097835	14.591794		
8	5.125831	13.137071	21.846151	25.688356	
9	5.758770	16.581719	31.163437	41.986386	
10	6.392453	20.431729	42.802061	64.882396	74.23342

TABLE B-3. POLE LOCATIONS AND QUADRATIC FACTORS $(S^2 + a_1 S + 1)$ OF MAXIMALLY FLAT MAGNITUDE (BUTTERWORTH) FUNCTIONS WITH PASSBAND 0 TO 1 rad/s*.

n	Poles	a_1
2	$-0.70711 \pm j0.70711$	1.41421
3	$-0.50000 \pm j0.86603$	1.00000
4	$-0.38268 \pm j0.92388$	0.76536
	$-0.92388 \pm j0.38268$	1.84776
5	$-0.30902 \pm j0.95106$	0.61804
	$-0.80902 \pm j0.58779$	1.61804
6	$-0.25882 \pm j0.96593$	0.51764
	$-0.70711 \pm j0.70711$	1.41421
	$-0.96593 \pm j0.25882$	1.93186
7	$-0.22252 \pm j0.97493$	0.44504
	$-0.62349 \pm j0.78183$	1.24698
	$-0.90097 \pm j0.43388$	1.80194
8	$-0.19509 \pm j0.98079$	0.39018
	$-0.55557 \pm j0.83147$	1.11114
	$-0.83147 \pm j0.55557$	1.66294
	$-0.98079 \pm j0.19509$	1.96158
9	$-0.17365 \pm j0.98481$	1.34730
	$-0.50000 \pm j0.86603$	1.00000
	$-0.76604 \pm j0.64279$	1.53208
	$-0.93969 \pm j0.34202$	1.87938
10	$-0.15643 \pm j0.99769$	0.31286
	$-0.45399 \pm j0.89101$	0.90798
	$-0.70711 \pm j0.70711$	1.41421
	$-0.89101 \pm j0.45399$	1.78292
	$-0.98769 \pm j0.15643$	1.97538

*All odd-order functions also have a pole at $S = -1$.

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Calculations of the a_k coefficients:

$$a_k = b_{n-k} - \binom{n}{k} c^k - \sum_{i=1}^{k-1} \binom{n-i}{k-i} a_i c^{k-i} \; ; \; k = 2,3, \ldots, n \qquad (14)$$

$$a_1 = b_{n-1} - Cn$$
$$= b_3 - Cn$$
$$= 1.1197386 - (0.2799347)(4)$$
$$= 0$$

$$a_2 = b_2 - \binom{4}{2} c^2 - \sum_{i=1}^{1} \binom{3}{1} (0) \; c^3$$

$$= b_2 - \binom{4}{2} c^2$$
$$= (1.716866) - (6)(0.2799347)^2$$
$$= 1.246686$$

$$a_3 = b_1 - \binom{4}{3} c^3 - \sum_{i=1}^{2} \binom{4-i}{3-i} a_i c^{3-i}$$

$$= 0.9377085 - \binom{2}{1} (1.246686)(0.2799347)$$

$$= 0.9377085 - 0.6979812$$
$$= 0.2397272$$

$$a_4 = b_0 - C^4 - \sum_{i=1}^{3} a_i c^{4-i}$$

$$= 0.379051 - 0.006140824 - \sum_{i=2}^{3} a_i c^{4-i}$$

$$= 0.379051 - (0.006140824) - (0.6710796)$$
$$= 0.2081076$$
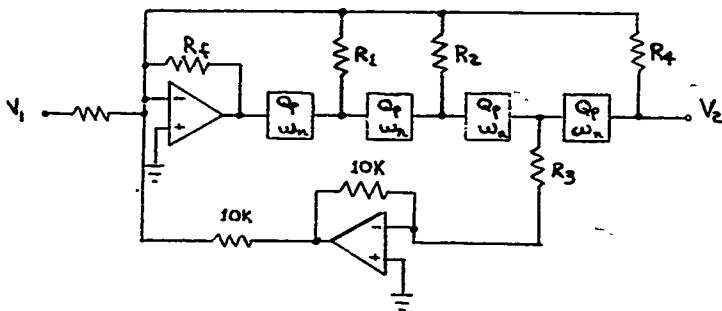
$H_0 = 2.4$

$f_0 = 3.33$ kHz

$BW = 350$ Hz

$Q = 9.51$

$$a_i = \frac{Rf}{Ri} \; ; \; i = 0,1,2, \ldots, n$$

Let Rf = 10 k

$$R_i = \frac{Rf}{a_i}$$

$$R_1 = \frac{10 \text{ k}}{0} = \infty$$

$$R_2 = \frac{10 \text{ k}}{a_2} = 8.02 \text{ k; actually used } 8.06 \text{ k}$$

$$R_3 = \frac{10 \text{ k}}{a_3} = 41.71 \text{ k; actually used } 41.2 \text{ k}$$

$$R_4 = \frac{10 \text{ k}}{a_4} = 48.05 \text{ k; actually used } 47.5 \text{ k} + 523\Omega$$

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All 4 filter blocks are identical.

$$H = \frac{Rf}{b_3 R} = \frac{26.38167 \times 10^3}{R_0}$$

$$H = 2.4$$

$$R_0 = 10.99 \text{ k}$$

To realize the above filter block Biquad (or Resonator), 2nd Order Band-pass filters will be used since they are highly stable for high values of Q and are relatively easy to tune.

$$\omega_n = 2\pi \ (3.33 \text{ kHz}) = 20.9230 \text{ krad/s}$$

$$Q_0 = \frac{Qn}{b_{n-1}} = \frac{(9.514)(4)}{1.1197386} = 33.98650 \cong 34$$
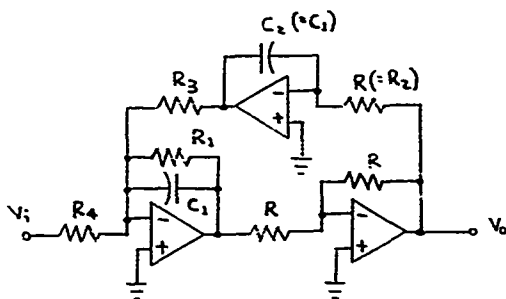
Biquad (Resonator) Band-pass Filter

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By applying the Low-pass to Band-pass transformation

$$\frac{V_2}{V_1}\bigg|_{LP} = \frac{kC}{s + C} \quad ; \ C=1$$

$$\frac{V_2}{V_1}\bigg|_{BP} = \frac{H_0\left(\dfrac{\omega_0}{Q}\right)s}{s^2 + \left(\dfrac{\omega_0}{Q}\right)s + \omega_0^2} \quad ; \ \text{2nd Order Band-pass Transfer Function}$$

Select C_1 near $10/f_0$ μF

$$R_1 = \frac{1}{\rho\omega_0 C_1}$$

$$R_2 = \frac{1}{\beta\omega_0 C_1} = \frac{\rho}{\beta} R_4$$

$$R_3 = \frac{1}{\omega_0^2 C_1^2 R}$$

where R is entirely arbitrary. ρ and β are as determined on page B-10.

The first filter block design with f_0 = 3.33 kHz, $Q\rho$ = 34, and a gain of 1 proved to have a center frequency of 3.33 kHz, but when the individual filter blocks were cascaded as in the PRB realization, the Q of approximately 10 was not observed and in fact the observed Q was near 30.

The second alternative was to design each of the filter blocks using the resonator as before, but the value of $Q\rho$ was instead changed to 10, the center frequency was left unchanged, and the gain was chosen to be 2.4.

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The design is as follows:

$f_c = 3.33$ kHz
$BW = 350$ Hz
$Q = 9.514$
$\omega_0 = 20,923.01$ krad/s

$$\frac{V_0}{Vi} = \frac{\rho \omega_G s}{s^2 + \beta \omega_0 s + \gamma \omega_0^2}$$

NOTE: For identical cascaded filter blocks $\gamma = 1$. γ (gamma) controls the type of resultant filter when a cascaded realization is used.

$$\rho = \frac{H_0}{Q} = \frac{2.4}{9.514} = 0.2523$$

$$\beta = \frac{1}{Q} = 0.10511$$

$\gamma = 1$; Choose $C_1 = 0.01$ μF, $R = R_2 = 10$ k

$$R_4 = \frac{1}{\rho \omega_0 C_1} = 18.95 \text{ k} \text{ ; actually used } 12.1 \text{ k} + 6.98 \text{ k}$$

$$R_2 = \frac{\rho}{\beta} R_1 = 45.47 \text{ k} \text{ ; actually used } 45.3 \text{ k}$$

$$R_3 = \frac{1}{\gamma \omega_0^2 C_1^2 R} = 2.28 \text{ k} \text{ ; actually used } 2.26 \text{ k}$$

Final PRB Filter with Cascaded 2nd Order Resonator Band-pass Filters

The filter shown in Figure B-1, when tested, exhibited the desired center frequency and bandwidth but did not quite respond as a typical Chebychev filter. Instead, it closely exhibited Butterworth characteristics. At any rate, the gain can be adjusted without affecting the filter performance by varying the 20 kΩ input potentiometer. The center frequency may be adjusted by varying either of the resistors, R_2 or R_3, indicated in the Figure on page B-23.
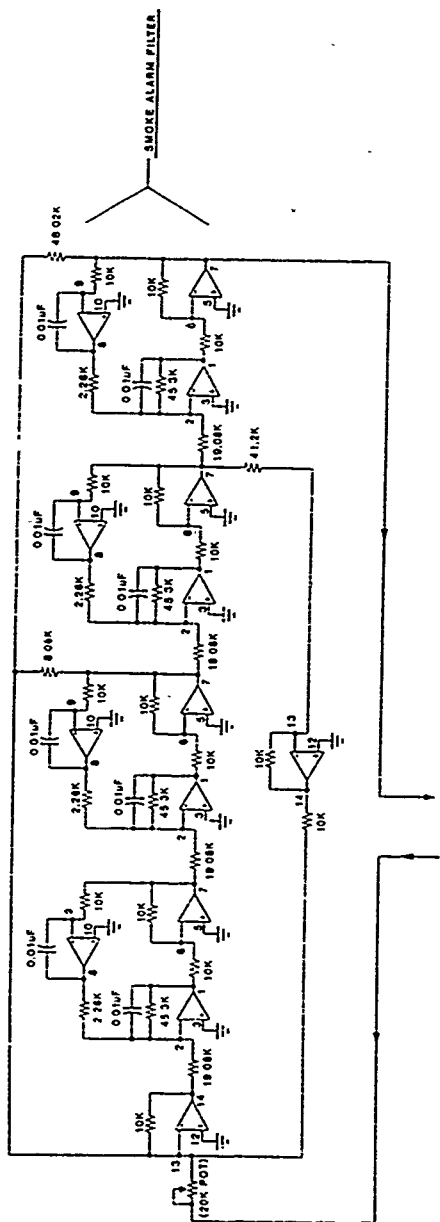
Figure B-1. Final PRB Filter With Cascaded 2nd-Order Resonator Band-Pass Filters.

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Noise Filter Design

The filter that is to establish the reference noise level is not as critical as the alarm filter. Therefore, a much simpler design can be used. The type of filter that will be used is a 4th-order multiple-feedback band-pass filter. Two multiple-feedback 2nd-order band-pass filters will be cascaded to realize a 4th-order Butterworth filter. The analysis of the MFB filter tends to be much more complex than that of the resonator, but two fewer op-amps are used in the MFB filter block. Basically, the analysis is a process of writing node equations for a y-parameter three-port network. The individual filter block schematic is shown below.

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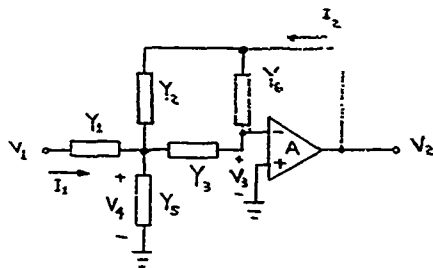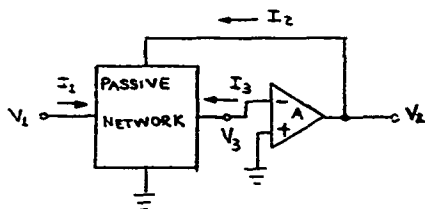
$$\begin{vmatrix} I_1 \\ I_2 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} Y_1 & 0 & 0 & -Y_1 \\ 0 & y_2 + y_6 & -Y_6 & -Y_2 \\ 0 & -Y_6 & Y_2 + Y_6 & -Y_3 \\ -Y_1 & -Y_2 & -Y_3 & Y_1 + Y_2 + Y_3 + Y_5 \end{vmatrix} \begin{vmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \end{vmatrix}$$

Admittance Matrix

After performing the required algebra, the voltage transfer function becomes the simplified form below:

$$\frac{V_2(s)}{V_1(s)} = \frac{-Y_1 Y_3}{Y_6(Y_1 + Y_2 + Y_3 + Y_5) + Y_2 Y_3} \tag{1}$$

$$\left. \frac{Y_2(s)}{Y_1(s)} \right|_{\text{Band-pass}} = \frac{H_0 \left(\dfrac{\omega_0}{Q}\right) s}{s^2 + \left(\dfrac{\omega_0}{Q}\right) s + \omega_0^2} \tag{2}$$

To realize a band-pass filter from equation (1) the denominator is

$$D(s) = Y_o(Y_1 + Y_2 + Y_3 + Y_5) + Y_2 Y_3 \tag{3}$$

and by examining the denominator, there are two possibilities for a band-pass filter. One is with $Y_1 = G_1$ and $Y_3 = sC_3$.

$$D(s) = Y_6(G_1 + Y_2 + sC_3 + Y_5) + Y_2 sC_3 \tag{4}$$

$D(s)$ now needs to be a second-order function. To realize this, $Y_2 = sC_2$, $Y_5 = G_5$, and $Y_6 = G_6$

$$\frac{V_2(s)}{V_1(s)} = \frac{-sG_1 C_3}{G_6(G_1 + sC_2 + sC_3 + G_5) + s^2 C_2 C_3} \tag{5}$$

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The alternate form of Equation (5) is:

$$\frac{V_2(s)}{V_1(s)} = \frac{-\left(\dfrac{1}{R_1 C_2}\right) \cdot s}{s^2 + s\left(\dfrac{1}{R_6 C_3} + \dfrac{1}{R_6 C_2}\right) + \dfrac{1}{R_6 C_2 C_3}\left(\dfrac{1}{R_1} + \dfrac{1}{R_S}\right)}$$ (6)

$$= \frac{-H_0\left(\dfrac{\omega_0}{Q}\right) s}{s^2 + s\left(\dfrac{\omega_0}{Q}\right) + s^2} \quad ; \text{ 2nd Order General Band-pass Transfer Function.}$$
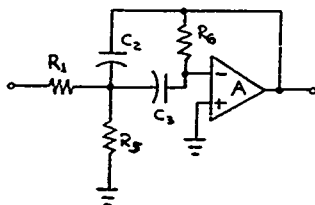
Multiple-Feedback Band-Pass Filter

$$H_0 = -\left(\frac{R_6}{R_1}\right)\left(\frac{C_2}{C_2 + C_3}\right) \; ; \text{ Let } C_2 = C_3 = C$$

Then $\quad H_0 = -\dfrac{R_6}{2R_1} \quad$ Gain

$$\omega_0 = \sqrt{\frac{1}{R_6 C^2}\left(\frac{1}{R_1} + \frac{1}{R_S}\right)} \quad \text{Center Frequency } \omega_0 = 2\pi f_0$$

$$Q = \left(\frac{2}{R_S C^2}\right)\sqrt{\frac{1}{R_6}\left(\frac{1}{R_1} + \frac{1}{R_S}\right)} \quad \text{Quality Factor} \quad Q = \frac{\omega_0}{BW}$$

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The noise filter is designed as a fourth order Butterworth Band-Pass filter with a center frequency of 1 kHz and a bandwidth of 1 kHz, which means that Q = 1. Since band-pass functions are obtained by applying the low-pass to band-pass transformation

$$s = \frac{Q(s^2 + \omega_0^2)}{\omega_0 s},$$

consequently, the order of a band-pass filter is twice that of its corresponding low-pass transfer function.

$$\omega_0 = \sqrt{\omega_u \omega_L}$$
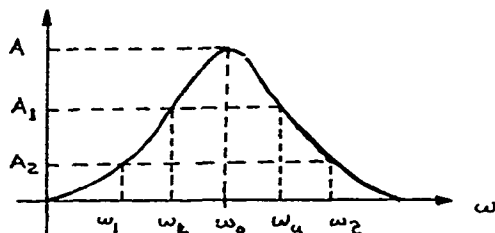
$$\omega_L = \omega_0 \left(-\frac{1}{2Q} + \sqrt{1 + \frac{1}{4Q^2}} \right)$$

$$\omega_u = \omega_0 \left(-\frac{1}{2Q} + \sqrt{1 + \frac{1}{4Q^2}} \right)$$

First Order Low-Pass Factor:

$$\frac{V_2}{V_1} = \frac{kC}{s + C}$$

Band-Pass Factor:

$$\frac{V_2}{V_1} = \frac{kC\left(\dfrac{\omega_0}{Q}\right)s}{s^2 + C\left(\dfrac{\omega_0}{Q}\right)s + \omega_0^2}$$

$$C = 1: \quad \frac{V_2}{V_1} = \frac{H_0\left(\dfrac{\omega_0}{Q}\right)s}{s^2 + \left(\dfrac{\omega_0}{Q}\right)s + \omega_0^2} \quad ; \text{ 2nd Order BP}$$

Butterworth or Chebychev band-pass transfer functions arising from 2nd order low-pass stages are of the form:

$$\frac{V_2}{V_1} = \frac{kC(\omega_0^2/Q^2)s^2}{s^4 + (B\omega_0/Q)s^3 + (2 + C/Q^2)\omega_0^2 s^2 + (B\omega_0^3/Q)s^4\omega_0^4}$$

Let $\dfrac{V_2}{V_1} = \left(\dfrac{V_2}{V_1}\right)1 \left(\dfrac{V_2}{V_1}\right)2$

Then $\dfrac{V_2}{V_1}$ may be factored into two 2nd order functions

$$\left(\frac{V_2}{V_1}\right)1 = \frac{(k_1\omega_0 \sqrt{C}/Q)s}{s^2 + (D\omega_0/E)_s + D^2\omega_0^2} \tag{1}$$

$$\left(\frac{V_2}{V_1}\right)2 = \frac{(k_2\omega_0 \sqrt{C}/Q)s}{s^2 + (\omega_0/DE)_s + \omega_0^2/D^2} \tag{2}$$

$$E = \frac{1}{B}\sqrt{\frac{C + 4Q^2 + \sqrt{(C + 4Q^2)^2 - (2BQ)^2}}{2}}$$

$$D = \frac{1}{2}\left[\frac{BE}{Q} + \sqrt{\left(\frac{BE}{Q}\right)^2 - 4}\right]$$

Thus, the transfer function of a Butterworth or Chebychev BP filter of order $\bar{n}$ = 4, 6, 8, ... will have a factor like Equations (1) and (2) for each 2nd order low-pass (LP) stage. Fourth Order Butterworth Band-Pass stage

f_0 = 1 kHz, BW = 1 kHz, Q = 1

ω_0 = $2\pi f_0$ = 6,283.185 rad/s

The gain of the noise filter should be approximately the same as the gain of the alarm filter. Preferably the noise filter gain should be at least a little more than the gain of the alarm filter for reasons that were introduced and discussed at the beginning of this report.
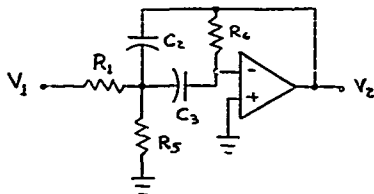
2nd-Order Multiple-Feedback Filter

In general

$$\frac{V_2}{V_1}\Bigg|_{BP} = \frac{\rho\omega_0 S}{S^2 - \beta\omega_0 S + \gamma\omega_0^2}$$

Specifications:

k_1 = 1.5, k_2 = 1.6, w_0 = 6.283 krad/s, Q = 1, H_0 = k = $k_1 k_2$ = 2.4 from page B-31 and Table B-4 below.

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TABLE B-4. BUTTERWORTH AND CHEBYSHEV LOW-PASS FILTER DATA.

N = 2			N = 3			N = 4	
Butterworth			Butterworth			Butterworth	
	B	C		B	C	B	C
	1.414214	1.000000		1.000000	1.000000 1.000000	0.765367 1.847759	1.000000 1.000000
Chebyshev			Chebyshev				
PRW	B	C	PRW	B	C		
0.1	2.372356	3.314037	0.1	3.969406 ---	1.689747 0.969406		
0.5	1.425625	1.516203					
			0.5	0.626456 ---	1.142448 0.626456		
0.1	1.097734	1.102510					
2.0	0.803816	0.823060	1.0	0.494171 ---	0.994205 0.494171		
3.0	0.644900	0.707948					
			2.0	0.368911 ---	0.886095 0.368911		
			3.0	0.298620 ---	0.839174 0.286620		

This table is used because a low-pass to band-pass transformation involves a band-pass transfer function of order n and, when transformed into a band-pass transfer function, the order of the resultant transfer function is increased by a factor of 2.

Low-pass (order = n), transforms to band-pass (order = 2n) with n = 2, Table B-4 data gives B = 1.414214, C = 1.

Select a standard value of C_2 near $10/f_0$ μF, and next a standard value of C_3 satisfying

$$C_3 > \frac{C_1 (\rho\beta - \gamma)}{f}$$

The resistances are found from:

$$R_1 = \frac{1}{\rho \omega_0 C_2}$$

$$R_5 = \frac{\beta}{[C_2(\gamma - \rho\beta) + \gamma C_3]\omega_0}$$

$$R_6 = \frac{1}{\beta\omega_0}\left(\frac{1}{C_2} + \frac{1}{C_3}\right)$$

For an even multiple order filter:

$$\rho = \frac{k_1\sqrt{C}}{Q} \qquad\qquad \rho = \frac{k_2\sqrt{C}}{Q}$$

$$\beta = \frac{D}{E} \quad \text{and the other} \quad \beta = \frac{1}{DE}$$

$$\gamma = D^2 \qquad\qquad \gamma = \frac{1}{D^2}$$

D and E are shown on page 101.

Calculations

$$C = 1 \qquad\qquad B = 1.414214$$

$$E = \frac{1}{1.414214}\sqrt{\frac{1 + 4 + \sqrt{(1+4)^2 - [(2)(1.414214)]^2}}{2}} = 1.510223$$

$$D = \frac{1}{2}\left(\left(\frac{(1.414214)(1.510223)}{1}\right) + \sqrt{\left(\frac{(1.414214)(1.510223)}{1}\right)^2 - 4}\right)$$

$$= 1.442574$$

$$\rho_1 = 1.5 \qquad\qquad \rho_2 = 1.6$$
$$\beta_1 = 0.9552060 \qquad \beta_2 = 0.4590086$$
$$\gamma_1 = 2.08120 \qquad\quad \gamma_2 = 0.4850336$$

$$\left(\frac{V_2}{V_1}\right)_1 = \frac{(9,425.10^3)s}{s^2 + 6.2832.10^3 S + 39.478.10^6}$$

$$\left(\frac{V_2}{V_1}\right)_2 = \frac{(0.05310.10^3)s}{s^2 + 6.2832.10^3 s + 39.478.10^6}$$

$$\frac{V_2}{V_1} = \left(\frac{V_2}{V_1}\right)_1 \left(\frac{V_2}{V_1}\right)_2 = 2.4$$

Gain = 2.4

f_0 = 1 kHz

$B\omega$ = 1 kHz

$Q = \dfrac{f_0}{B\omega} = 1$
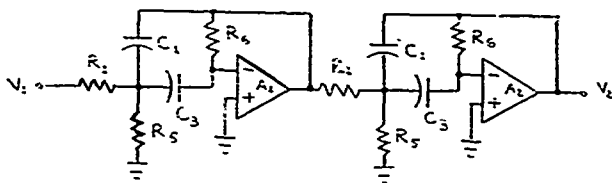
Final Noise Filter; 4th Order Butterworth Band-Pass Filter

$C_2 = C_3 = 10/f_0 \; \mu F = 0.01 \; \mu F$, both stages

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Stage 1	Actually Used	Stage 2	Actually Used
$R_1 \approx 10.61$ k	20 k pot.	$R_1 = 9.95$ k	10 k
$R_5 \approx 5.57$ k	5.49 k + 80 Ω	$R_5 = 32.23$ k	31.6 k + 619 Ω
$R_6 = 33.32$ k	33.2 k	$R_6 = 69.35$ k	68.1 k + 1.18 k

$$H_0 = \frac{R_6}{2R_1} = \text{Gain}$$

$$\omega_0 = \sqrt{\frac{1}{R_6 C_2^2} \left(\frac{1}{R_1} + \frac{1}{R_5}\right)} = \text{Center Frequency}$$

$$Q = \left(\frac{2}{R_6 C_2^2}\right)\sqrt{\frac{1}{R_6} \left(\frac{1}{R_1} + \frac{1}{R_5}\right)} = \text{Quality} = \frac{\omega_0}{BW}$$

The gain may be adjusted by varying R_1. The center frequency may be adjusted by varying both R_5 and R_6 without affecting Q. Q may be adjusted by varying R_5.

The next section in the alarm receiver performs the actual alarm discrimi-nation. It consists of two half-wave rectifiers, two damped integrators, a sub-tractor circuit, and a Schmitt trigger. The half-wave rectifiers are actually negative half-wave rectifiers. This was done so that the output of the damped integrators, which are inverting, will be at a positive potential.
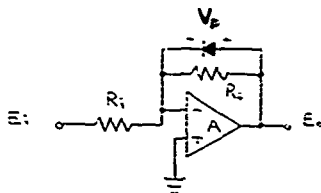
Negative 1/2-Wave Rectifier

When Ei becomes sufficiently negative, Eo will, in turn, become positive and the diode will come on.

when Ei $= -\left(\dfrac{V_D}{Rf}\right)$ Ri, Eo will be clamped at $+ V_D$. For Ei above $-\left(\dfrac{Ri}{Rf}\right)V_D$

volts, Eo will equal $-\left(\dfrac{Rf}{Ri}\right)$ Ei.
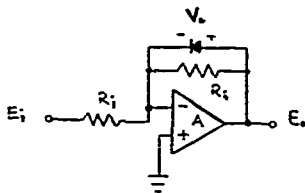
Negative 1/2-Wave Rectifier

For R_i = 1k, R_f = 8.06, V_D = 0.7 Volt

Limits for E_0: $-12 V < E_0 < + 0.7 V$

When E_i = -86.85 mV $\rightarrow$ E_0 = +0.7 volt.

The half-wave rectifier will saturate (negatively) at $E_0 \cong -12$ V when Ei is greater than +1.5 volts.

The output from the two filters are the inputs for the two 1/2-wave rectifiers. The output from the rectifiers is directed to the input of the inverting damped integrators.

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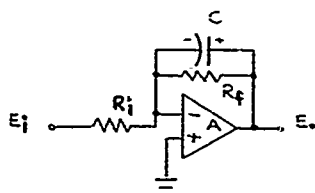
Damped Integrator

The damped integrator can be thought of as a low-pass filter with its pole displaced from the origin. The transfer function for the damped integrator is:

$$\frac{E_0}{E_i} = -\frac{\left(R_f \parallel \frac{1}{j\omega C}\right)}{R_i} = -\frac{R_f}{R_i}\left(\frac{1}{1 + j\omega R_f C}\right)$$

The integrators serve two purposes. The first is that they will damp any large high frequency noise spike. The second and most important purpose they serve is they provide the appropriate voltage level corresponding to the output from the noise filter and the alarm filters.

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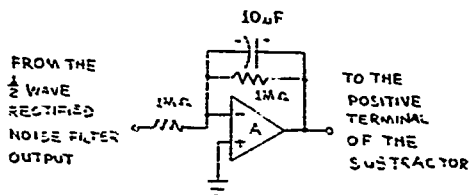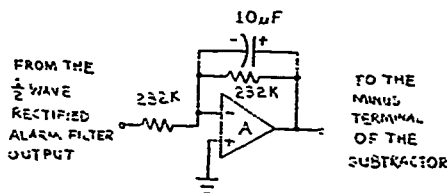
The output from the two integrators is a dc voltage representation of the half-wave rectified output from the two filters. The output from the integrators is then applied to subtractor shown below.
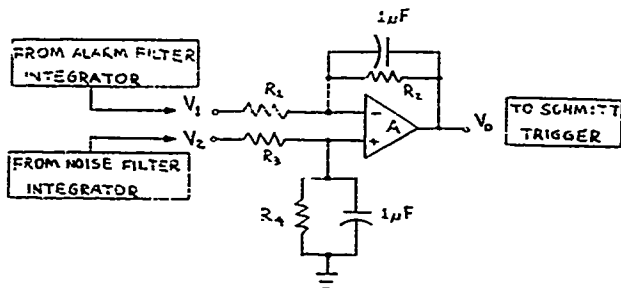
For the minimum offset error due to the input bias current, make

$$R_1 \| R_2 = R_3 \| R_4$$

If $R_1 = R_2 = R_3 = R_4$, then
$$V_0 = (V_2 - V_1)$$

The 1 µF capacitors help stabilize the input voltages.

For the subtractor used in the discriminator $R_1 = R_2 = R_3 = R_4 = 100$ kΩ.

The output of the subtractor is fed into the Schmitt trigger. When no alarm is occuring, the output of the subtractor is sitting at a positive voltage since V_2 will be somewhat greater than V_1, where V_1 and V_2 are the input subtractor voltages. With the output of the subtractor at a positive voltage, the Schmitt trigger's output will be at approximately +11 volts dc, indicating no alarm is present. When an alarm is detected, the output of the alarm integrator

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begins to increase. When this voltage becomes greater than the Schmitt trigger reference voltage, plus an additional voltage equal to the Schmitt trigger's "trigger window" voltage, the output of the Schmitt trigger will quickly drop to about -10 volts dc indicating a possible alarm has occurred.
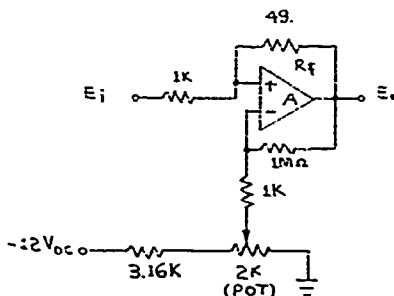
Schmitt Trigger

The basic theory behind the operation of a Schmitt trigger is to apply positive feedback to an amplifier so that when an input transition occurs, the amplifier will momentarily operate in its linear region, thus amplifying the input. But since there is positive feedback from the output to the input, the momentarily amplified output will be fed back into the input until the input voltage is large enough to saturate the amplifier and cause the output to switch to approximately the supply voltage. The positive feedback resistor (R_f) above controls the triggering window or the upper and lower trigger levels. Where the trigger window equals the difference between the upper and lower trigger levels, as Rf increases, the trigger window decreases. The voltage at the inverting (-) terminal of the op-amp can be changed to adjust the voltage at which Ei must at least be close to before the output can trigger. This is done by using a

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voltage divider with a potentiometer. The trigger level adjustment can also be thought of in terms of a sensitivity adjustment. As the trigger level is made more positive, E_i does not have to drop as much before the output triggers, and vice versa. The trigger cannot be made too high or low or the circuit will not operate properly.

The output of the Schmitt trigger is inverted and then shifted to logic levels with a transistor switch. The output of the transistor switch will be at logic zero or zero volts when the smoke detector alarm is not present. When the smoke detector alarm is present, the output of the transistor switch will be at a logic 1 or equivalently at +5 volts dc.

For the alarm to be co..idered valid, the output from the transistor switch must remain high, +5 volts, for at least 15 seconds. If the output momentarily drops out for less than approximately 5 seconds, and then rises to the +5 volts, the 15-second timer will not be reset. In other words, when the alarm is detected, the Schmitt trigger drops to -10 volts and then is inverted and level shifted to a logic level. The output is now at +5 volts. This sic 1 is then used to trigger a 15-second timer which will delay the +5 volts for an equivalent time. If the alarm signal drops out for more than 5 seconds, the timer will be reset. Otherwise when the 15-second delay time has run out, the discriminator has verified that a possible fire has been detected. A simplified schematic of the delay circuit is shown below.
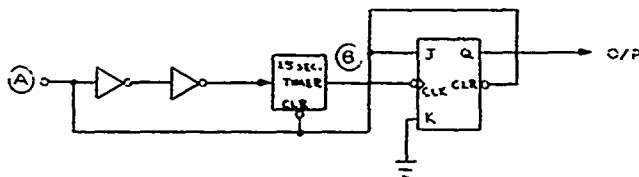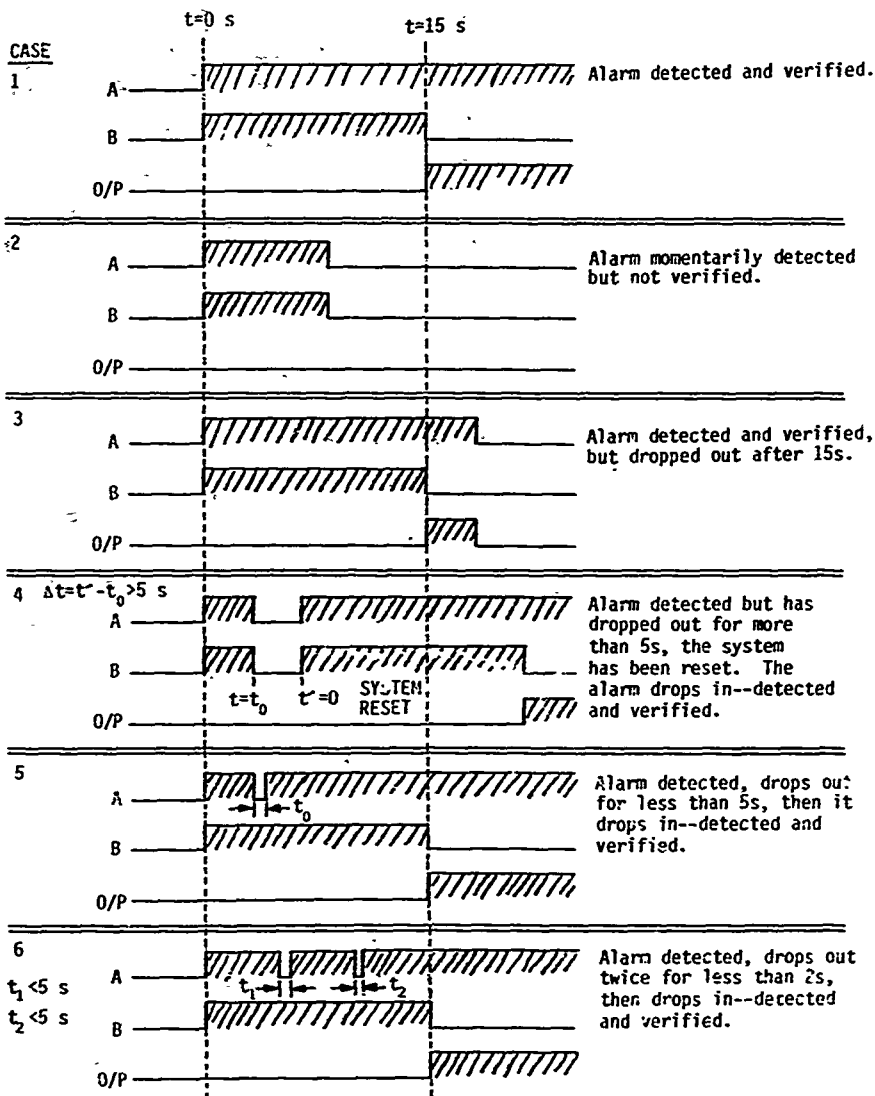
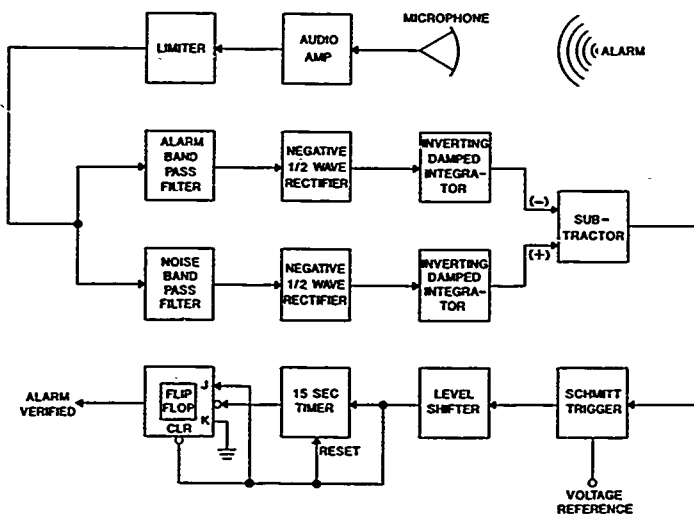Figure 8-2. Alarm Receiver Timing Diagrams.
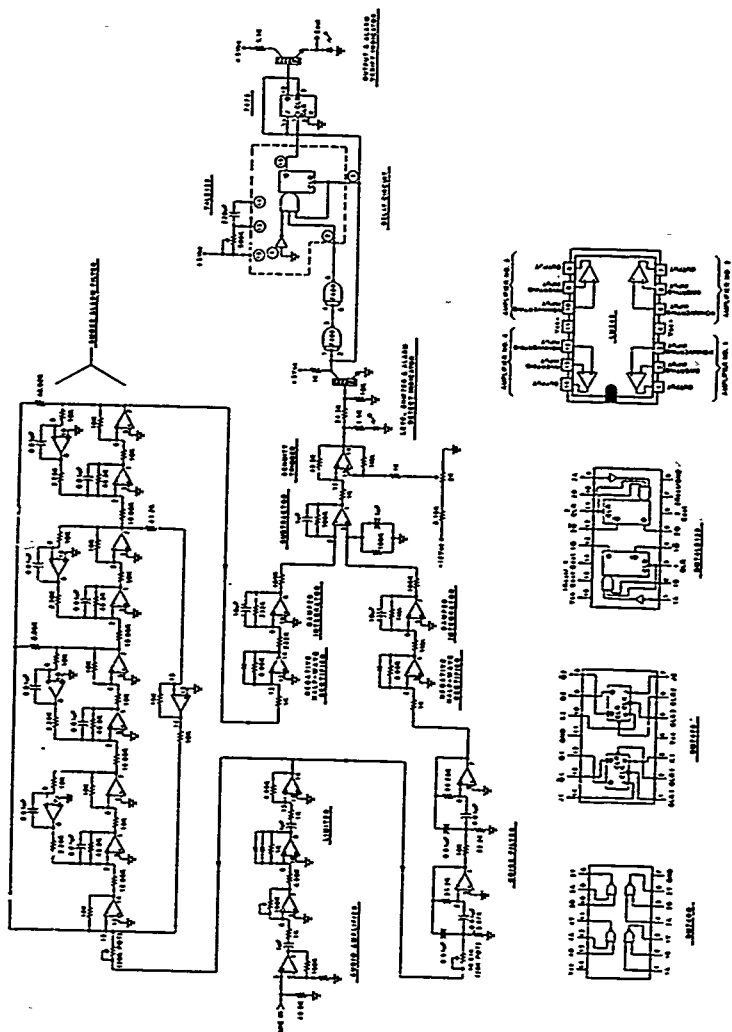
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Figure B-3. Alarm Receiver Block Diagram.

Figure B-4. Alarm Receiver Electrical Schematic.

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APPENDIX C
SMOKE DETECTOR RESPONSE TESTS

TABLE C-1. 3 1/2-inch DIAMETER FUEL CUP SMOKE DETECTOR TESTS.

Test Number	Detector Type	Manufacturer	Cabinet Fans	Time to Detect Smoke, Seconds
39	Photoelectric	BRK	On	102
40	Photoelectric	BRK	On	83
41	Photoelectric	BRK	Off	31
42	Photoelectric	BRK	Off	38
43	Ionization	Tandy	On	9
44	Ionization	Tandy	On	13
45	Ionization	Tandy	Off	18
46	Ionization	Tandy	Off	17
47	Photoelectric/Ionization	Dicon	On	42
48	Photoelectric/Ionization	Dicon	On	42
49	Photoelectric/Ionization	Dicon	Off	13

TABLE C-2. 115-VOLT TRANSFORMER SMOKE DETECTOR TESTS.

Test Number	Detector Type	Manufacturer	Cabinet Fans	Time to Detect Smoke, Seconds
51	Photoelectric/Ionization	Dicon	On	15
52	Ionization	Tandy	On	17
53	Photoelectric	BRK	On	17

TABLE C-3. PVC INSULATION SMOKE DETECTOR TESTS.

Test Number	Detector Type	Manufacturer	Cabinet Fans	Time to Detect Smoke, Seconds
54	Ionization	Tandy	Off	46
55	Photoelectric	BRK	Off	11
56	Photoelectric/Ionization	Dicon	Off	8
57	Photoelectric/Ionization	Dicon	Off	27
58	Photoelectric	BRK	Off	39
59	Ionization	Tandy	Off	15

This appendix is a reproduction of the approved "Test Plan, Capsulized
Extinguisher Device" submitted 14 August 1985. Thus, it is a self-contained
document with its own internally consistent numbering system for equations,
references, figures, and appendixes.

TEST PLAN

FOR

CAPSULIZED EXTINGUISHER DFVICE

SUBTASK NUMBER 3.01

PREPARED BY

THE NEW MEXICO ENGINEERING RESEARCH INSTITUTE

FOR

THE AIR FORCE ENGINEERING AND SERVICES CENTER

CONTENTS

CAPSULIZED EXTINGUISHER DEVICE

TEST PLAN

Section I - Introduction

1.1 Objective - A series of tests will be conducted at Tyndall AFB to determine the effectiveness of the SAFECOMP capsulized extinguishing device to detect and extinguish fires in computer cabinets. SAFECOMP will be tested with a Univax 1050 mainframe computer located at building 21.

1.2 Background - The Air Force has developed a new concept in fire protection. This concept is a capsulized, remote and independent fire extinguisher. The purpose of this concept is to prevent large-scale damage, high-cost protection systems and interruption of critical service. The small capsulized devices can be located near ignition sources so that fires are sensed quickly and suppressed. Therefore, there is minimal heat and smoke generation that can damage electronic and other materials. It also generates an audible signal to warn personnel which may be present. This signal is also received and discriminated by a wall-mounted electronic system that sends a signal to a central fire alarm to notify the fire department. The capsulized extinguisher has been tested for suppressing fires in waste receptacles and computer cabinets in critical electronic facilities so clean and efficient halon fire suppressants were incorporated. This extinguisher/alarm system has desirable features for fire suppression inside computer cabinets whereby major losses and shutdown of computers could be avoided.

1.3 Scope - Two series of tests will be run to determine the suppressive abilities of Halon 1211 inside a computer cabinet. The first series of tests will use transformers inside the cabinets that are shorted on the secondary side. The second series of tests will use small cups with sponges soaked in alcohol fuel. Sponges with alcohol will be used because of the consistency and repeatability of each fire and smoke output.

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Section II - Description of Tests

2.1 Test Specimens - SAFECOMP is a cylinder containing ten to sixteen fluid ounces of Halon 1211. (See Figure 1.) The SAFECOMP is sealed with a one mil brass rupture disk. An ionization smoke detector with a 30 second delay is connected to a pyro-pneumatic actuated piston. The activated piston puncturing device is mounted in an enclosed cap directly above the rupture disk. A port to allow for the release of the Halon is on the side of the cap. The smoke detector is attached to the halon unit as a single package. When the smoke detector detects smoke it sets off a 85 Db electronic notifier (alarm). Thirty seconds after the smoke detector has detected the fire, a relay will close and send a current to the puncturing device. The current will ignite a very small charge which will send the piston into the rupture disc on the SAFECOMP. The rupturing of the disk will allow the halon to extinguish the fire. An electronic discriminator device with a microphone will be mounted in various locations in the computer facility. The discriminator package will recognize the frequency and decibel level emitted from the smoke detector's alarm. The discriminator is disigned to be wired into the circuit breaker panel for the computer room. When the discriminator recognizes the alarm from the smoke detector, it shuts off the power to all computer cabinets.

2.2 Test Facility - The SAFECOMP and discriminator will be tested at Tyndall AFB. A Univax 1050 mainframe computer will be used for the testing. The computer and peripheral equipment are contained in 13 separate cabinets. The SAFECOMP will be tested in 5 different cabinets.

2.3 Instrumentation and Photography - Each test will include data on temperature, air velocity, halon concentration and background room noise. The data taken will be zeroed to the moment the power is applied to the test transformer or the fuel source is ignited. The photo coverage will be normal-speed VCR. The photography will be synchronized with the other data collection.

Still photography will be required in the form of color slides and black and white negatives to document the pretest setup and posttest damage to the cabinet.
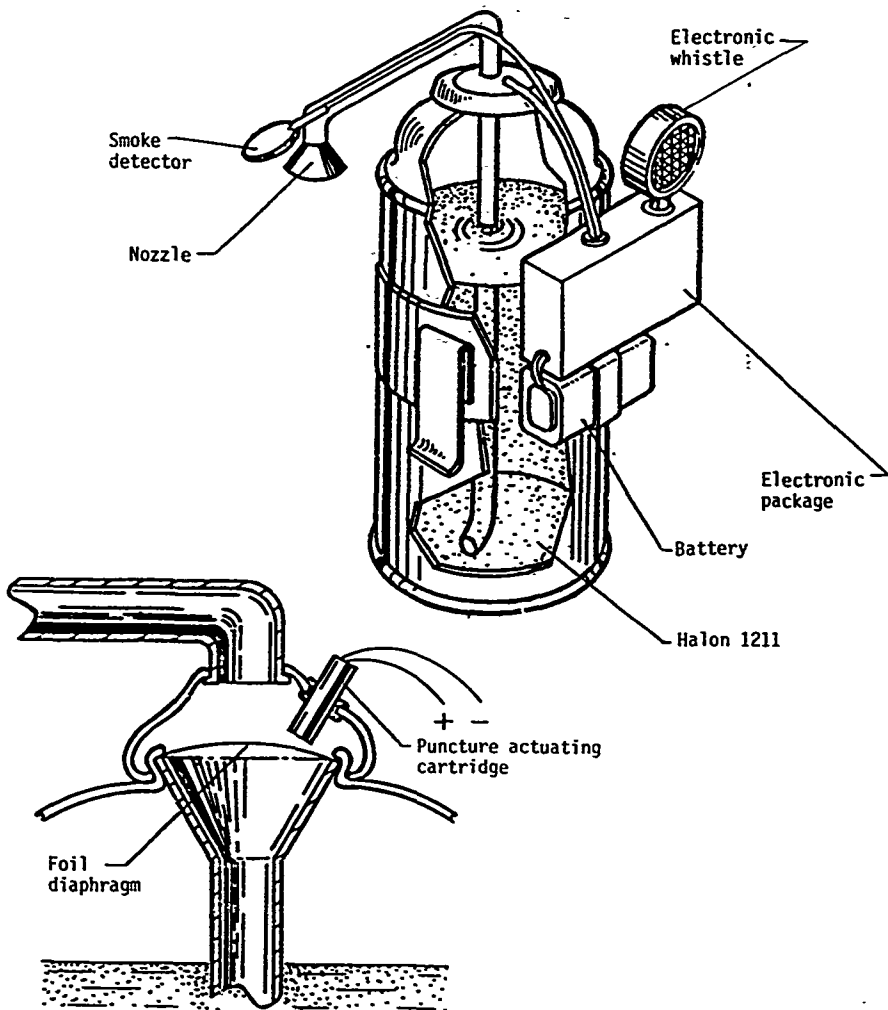
Figure 1. SAFECOMP actuation concept.

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2.4 Test Preparation - Preparation for the individual test series will proceed as follows:

1. Install SAFECOMP and alarm discriminators.

2. Install thermocouple gages, halon concentration analyzer, noise level meter and velometer. Hook up gages and test for functioning.

3. Position cameras.

4. Take pretest still photographs.

5. Position fuel source for appropriate test.

6. Evacuate nonessential personnel.

7. Conduct final check of cameras and instrumentation.

8. Apply power to transformer or ignite fuel source.

9. Manually disconnect power from cabinet and cabinet fans when No. 2 discriminator detects alarm.

2.5 Posttest Procedures - Immediately following each test event, the following actions shall be taken:

1. Evacuate halon from inside the computer room.

2. Take still photographs of damage in undisturbed situation.

3. Check instrumentation readings.

2.6 Testing

2.6.1 Test No. 1 - In the first test the SAFECOMP package will be placed on the top of the FASTRAND controller cabinet. The top of the cabinet has a grate with half inch opening to vent the air from the fans in the bottom of the cabinet. The SAFECOMP will be securely mounted to the grate. A large (8 inch x 8 inch) 115 volt ac transformer will be placed next to the existing power supply. The secondary of the transformer will be directly shorted by soldering all secondary wires together. This will cause the transformer to overheat, smoke and eventually burst into flames. The power cord will be run through an opening in the computer cabinet and attached to existing power outlets. Eight Type K thermocouples going to the Air Force instrumentaion van will be used to record the temperatures inside and outside of the computer cabinets. The eight thermocouples will be labeled 00 to 07. See instrumen-

tation plan for thermocouple locations. 00 will be placed 3 inches to the side of the primary side of the transformer. 01 will be in the same position on the secondary side of the transformer. Thermocouple 02 will be placed 3 inches directly above the transformer. 03 and 04 will be placed 12 inches above the primary and secondary sides of the transformer. 05 and 06 will be mounted 24 inches above and 12 inches offset from the transformer. 07 will be on the SAFECOMP. The location of three gas concentration gages will be six inches from the top, six inches from the bottom and in the vertical center of the cabinet. They all will be mounted on the horizontal center of the cabinet. Three discriminator boards will be mounted in various locations in the computer room. No. 1 will be mounted 15 feet away from the SAFECOMP. No. 2 will be mounted on a stand 25 feet from the SAFECOMP. No. 3 will be mounted in the farthest corner of the room not directly in line with the SAFECOMP. All doors on the cabinet will be closed to simulate a working computer. One panel of the cabinet will be plexiglas to permit video recording.

2.6.2 Procedure for Remaining Tests - In the next four tests, the same set-up will be used for the thermocouple placement, video equipment placement, and instrumentation. The discriminator boards will be kept in the same positions in conjunction with which computer cabinet is being used. The location of the fire source, the location of the SAFECOMP and the type of cabinet will all be different than test No. 1. The source for the smoke and flame will be a flammable liquid in two of the tests.

2.6.3 Test No. 2 - A transformer will be the source of smoke and flame and will be mounted in the bottom of the CPU cabinet. The SAFECOMP will be mounted horizontally in the upper inside corner of the cabinet.

2.6.4 Test No. 3 - A transformer will be the source of smoke and flame and will be mounted in the bottom of the communication cabinet. The SAFECOMP will be mounted horizontally outside of the cabinet on top.

2.6.5 Test No. 4 - A small cup with a sponge soaked in alcohol will be the source of smoke and flame. The flammable liquid will be placed close to the power supply and in the Tape Drive cabinet. The SAFECOMP will be mounted horizontally outside on top of the cabinet. The flammable liquid will be ignited by a hand torch. Timing will start as soon as the fuel is ignited. One panel of the cabinet will be plexiglas for video recording.

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2.6.6 Test No. 6 - A small cup with a sponge soaked in alcohol will be placed at the base of the Disc Drive cabinet. The SAFECOMP will be mounted in a vertical position on an inside wall close to the top of the cabinet. The flammable liquid will be ignited by a hand torch. Timing will start as soon as the fuel is ignited. One panel of the cabinet will be plexiglas for video recording.

Section III - Responsibilities -- The overall responsibility for the entire test program rests with the Test Director. In adition, he will be responsible for performance of the test event's countdown coordination and procedures, and any extraordinary safety and security precautions during test days. The Test Director will delegate his authority where necessary. Specific responsibilities relative to safety and instrumentation, are contained in the appendices.

APPENDIX A

SAFETY PLAN

1. **PURPOSE.** This safety plan establishes the safety areas for the testing site and all related functions thereto, to be conducted at Tyndall Air Force Base, Florida, and identifies the agency responsible for each of these areas. All references to the test throughout this safety plan will pertain to the tests to be conducted at Tyndall Air Force Base, Florida. The detailed safety rules which are applicable to this project are documented herein. Before any fire testing can be conducted at Tyndall Air Force Base, Florida, the Base Fire Chief must be notified and his approval received. The following safety documents are applicable to this test:

> AFOSH Standards
>
> AFR 127-4

2. **OVERALL SAFETY RESPONSIBILITY.** AFESC/RDCS as Test Director is responsible for enforcing the overall safety program for the test. The Base Fire Chief or his designated representative is the safety officer during all actual fire burns. The test Director is the safety officer for all other events at the test site. The Test Director will maintain close coordination with the Air Defense Weapons Center Ground Safety Officer on all safety matters.

3. **SAFETY AREAS.** The safety requirements of the test have been divided into three separate and distinct areas to facilitate the establishment of specific requirements for the different areas of operation. The three areas of safety requirements are divided into three areas as follows:

   a. General Safety.

   b. Construction Safety.

   c. Fire Safety.

4. **GENERAL SAFETY.** The responsibility for general site safety resides with AFESC. The authority to execute specific safety directives is delegated to the Test Director. The Public Affairs Office (AFESC/PA) is responsible for notification and publicizing the test (when applicable).

   a. **Safety Briefing.** The Test Director will brief all AFESC personnel and/or supervisors of construction crews on the safety hazards existing within the test site. Supervisors will, in turn, brief their personnel on these hazards.

   b. **Visitors.** Visitors shall not be allowed at the test site without approval of the Test Director or his authorized delegate. Visitors shall be instructed on applicable area safety regulations.

   c. **Individual Safety Responsibility.** Careful attention to the potential hazards involved in work dealing with fire must be stressed in all levels of responsibility. The purpose of the safety rules outlined herein is to present the most important elements in setting controlled fires. These rules do not cover all the possible hazards or safety precautions necessary at the site.

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As new problems arise, new safety measures will be established to cope with them. In the interim, common sense must be applied to ensure that safety prevails. This entire Safety Plan must be closely followed by all personnel and enforced by all supervisors. The procedures contained herein shall be accepted as minimum standards until such time as the Test Director, with the concurrence of the Base Fire Chief, authorizes deviation therefrom.

d. Vehicles. Speeds shall not exceed 20 mph when driving on unpaved roads. Seat belts will be used at all times while vehicles are in motion. When a vehicle is parked, the hand brake will be set and the transmission put in park or reverse.

e. Accident Reporting (Emergency).

(1) Scope. This standard procedure is intended as a guide to ensure expedient handling and care of personnel injured in an accident or disaster. All "post-emergency" reporting and investigation of an accident will be performed in accordance with application Air Force regulations and is not considered to be within the scope of this standard procedure.

(2) Responsibility. Every person involved in this program must be completely familiar with the emergency reporting procedures established by this plan and must implement these procedures immediately in the event of an accident. The Test Director must familiarize all supervisors with this standard procedure. The supervisor must familiarize subordinate personnel with the procedures established by this plan.

(3) Emergency Reporting Procedures. In the event of an accident at the test site, the following procedures will be followed:

(a) The senior supervisor at the scene of an accident will direct appropriate first aid. Caution will be exercised to prevent aggravation of an accident--related injury.

(b) Tyndall AFB Hospital Ambulance Service will be immediately notified by calling Extension 2333. The nature of the accident, including apparent condition of injured personnel and the location of the test site, will be reported to the medical personnel. The Test Director or, in his absence, the Senior Supervisor, shall determine whether to attempt transfer of the injured to a hospital or to request emergency ambulance support.

(c) The Test Director or, in his absence, the Senior Supervisor, shall determine the seriousness of an accitent. If the accident is not serious enough to require emergency hospitalization or ambulance service, the injured person will be taken to a doctor or hospital by normal means of transportation.

f. First Aid. An adequate supply of first-aid items will be maintained at the site. These items will be properly stored and periodically inspected to ensure their adequacy in case of an emergency.

g. Fire Prevention Reporting and Emergency Procedures. This paragraph defines the responsibility for fire prevention and reporting procedures related to the test.

(1) _Responsibility._ The Test Director will be responsible for the implementation of the procedures established by this plan. All onsite personnel must be completely familiar with these procedures to ensure proper response to an emergency.

(2) _Fire Prevention Procedures._ The procedures listed below are to be followed in an effort to reduce chances of an uncontrolled fire.

(a) Three portable fire extinguishers will be at the test site.

(b) The Test Director shall instruct all personnel on the procedures to follow in case of fire, and the location and use of available fire extinguishers.

APPENDIX B

INSTRUMENTATION PLAN

1. __PURPOSE:__ This plan describes the procedures and responsibilities for instrumentation and data collecting for this test program.

2. __PROCEDURES:__ For each of the tests, temperature, air velocity and gas concentration in the cabinet and background noise will be collected.

3. __SEQUENCE OF EVENTS:__

    a. The test events are as follows:

        (1) Power is applied to the test transformer (or the fuel source is ignited).

        (2) As smoke accumulates in the cabinet the smoke detector sets off the alarm.

        (3) After 15 seconds of true alarm signal the discriminator registers a true signal and the "fire detected" light goes on.

        (4) The power to the cabinet and cabinet fans is manually turned off.

        (5) After 30 seconds of true alarm signal from the smoke detector, the halon is released by the piston actuator.

        (6) Halon dumps for approximately 20 seconds and the fire is extinguished.

        (7) __RESPONSIBILITIES:__

            a. The instrumentation section is responsible for the entire data acquisition process, including:

                (1) Recording

                (2) Digitization

                (3) Quality assessment

                (4) Initial plotting

                (5) Corrections

                (6) Analysis of results

            b. AFESC will provide and/or install

                (1) The thermocouple gages which will be provided by the New Mexico Engineering Research Institute (NMERI).

                (2) Personnel support for system setup and operation.
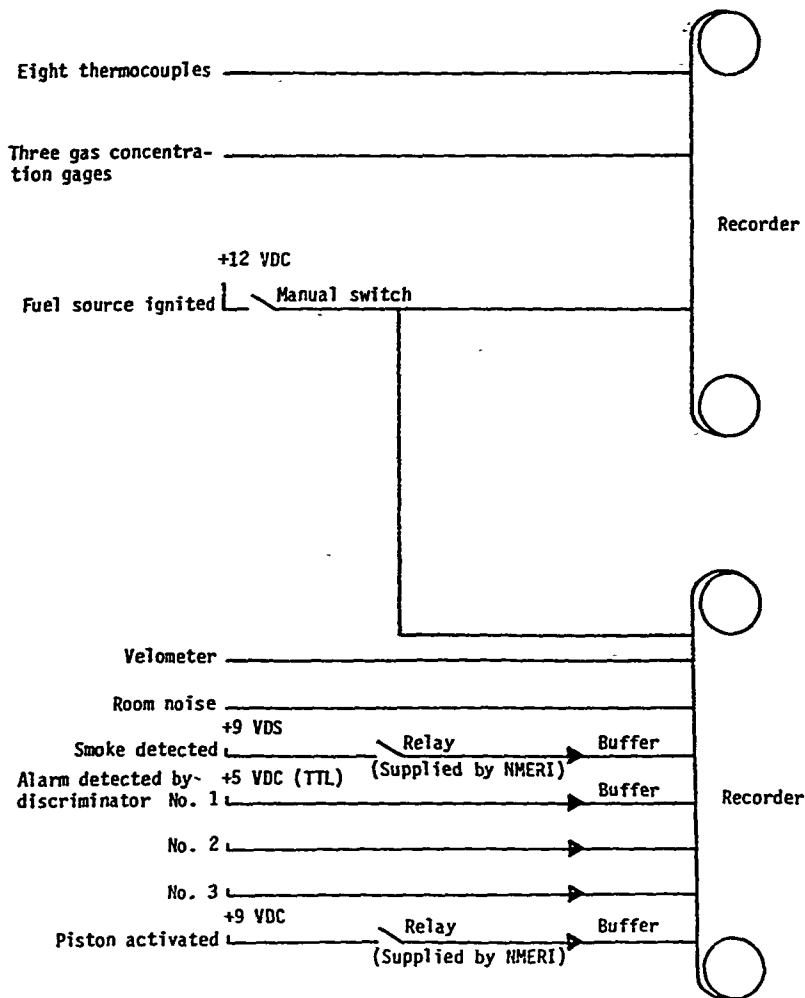
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4. INSTRUMENTATION.

Figure B-1. Instrumentation.

5. LIST OF TEST EQUIPMENT:

2 - 14 channel recorders or equivalent.

8 - Type K thermocouples

1 - Velometer

1 - Peerless 300 concentration analyzer

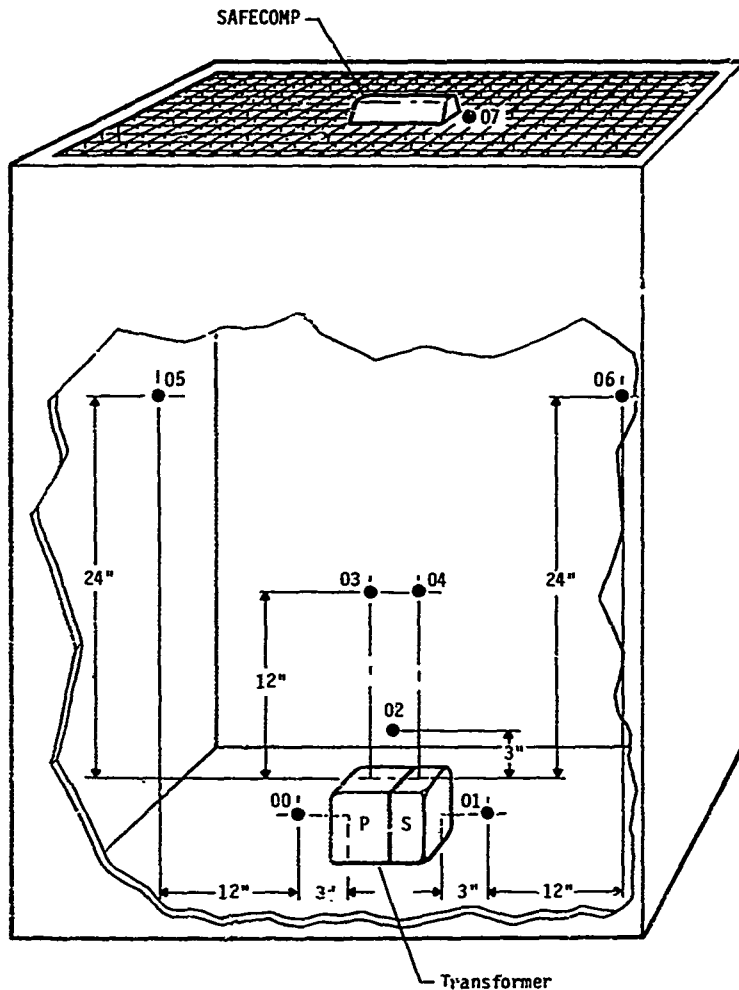1 - B & K noise level meter or equivalent

6. THERMOCOUPLE LOCATION:

Figure B-2. Thermocouple location.

APPENDIX E
SYSTEM EVALUATION TEST DATA

The data and results from the system evaluation tests at the Computer-Fire Test Facility, Tyndall Air Force Base, are contained in this Appendix.
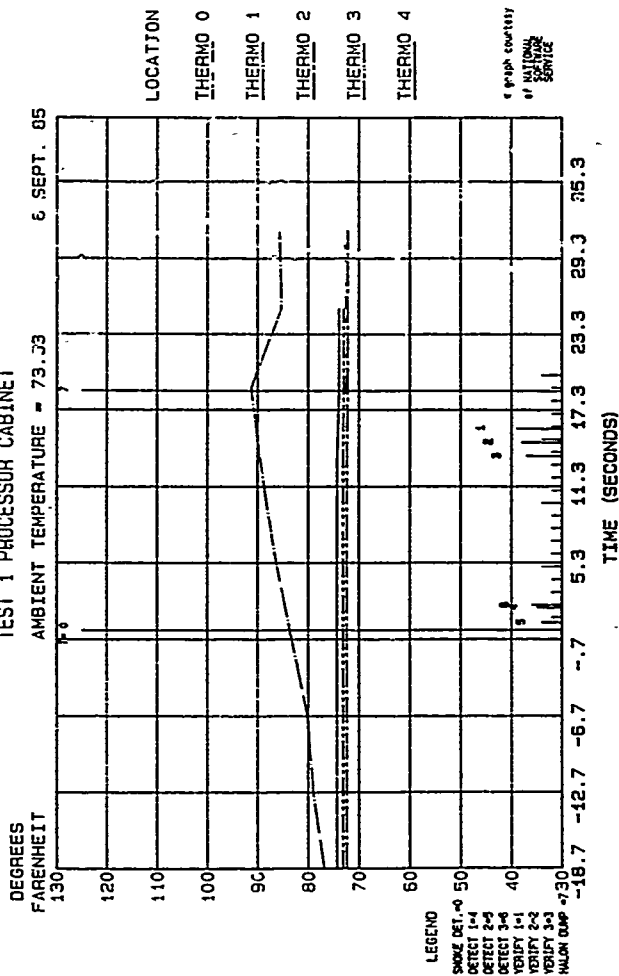
TABLE E-1. TEST CONDITIONS.

Test No.	Cabinet Description	Total Cabinet Volume, ft³	Cabinet[a] Volume Vacated, ft³	Cabinet Air Flow, ft/min	Amount of Halon, lb	Theoretical Concentration, Percent	Fire Source	Fire Location
1	Processor unit	31.5	23.7	210	1.0	9	Transformer	Bottom
2	Processor unit	31.5	23.7	210	1.0	9	Fuel Cup	Bottom
3	FASTRAND unit	26.4	19.8	275	1.0	10.8	Transformer	Middle
4	FASTRAND unit	26.4	19.8	275	1.0	10.8	Transformer	Middle
5	Tape drive unit	26.2	19.6	80	1.0	10.9	Transformer and fuel cup	Middle Bottom

[a]Cabinet volume vacated was estimated in each case assuming that the cabinet was 25 percent full of equipment (75% empty).

Note: In all tests, the extinguisher unit was located on top of the test cabinet.

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SAFE COMP TEST: TYNDALL AFB
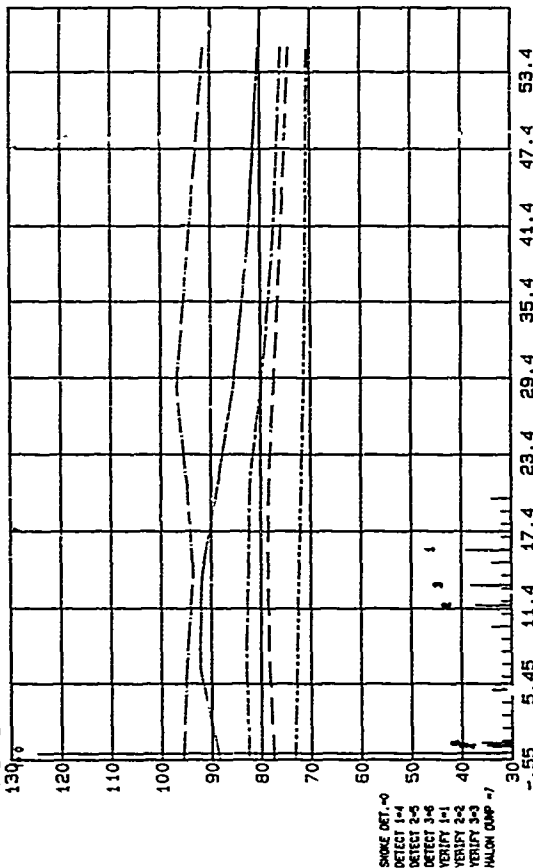COMPUTER-FIRE TEST FACILITY

TEST 1 PROCESSOR CABINET

AMBIENT TEMPERATURE = 73.33   6 SEPT. 85

LOCATION

THERMO 0
THERMO 1
THERMO 2
THERMO 3
THERMO 4

graph courtesy of NATIONAL COMPUTER SERVICE

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SAFE COMP TEST: TYNDALL AFB
COMPUTER-FIRE TEST FACILITY:

TEST 2 PROCESSOR CABINET

AMBIENT TEMPERATURE = 74.74   9 SEPT. 85

LOCATION

THERMO 0
THERMO 1
THERMO 2
THERMO 3
THERMO 4

graph courtesy
of NATIONAL
SOFTWARE
SERVICE

DEGREES
FARENHEIT

TIME (SECONDS)

SAFE COMP TEST: TYNDALL AFB
COMPUTER-FIRE TEST FACILITY

TEST 3 FASTRAND CABINET

AMBIENT TEMPERATURE = 76.32   9 SEPT. 85

LOCATION

THERMO 0

THERMO 1

THERMO 2
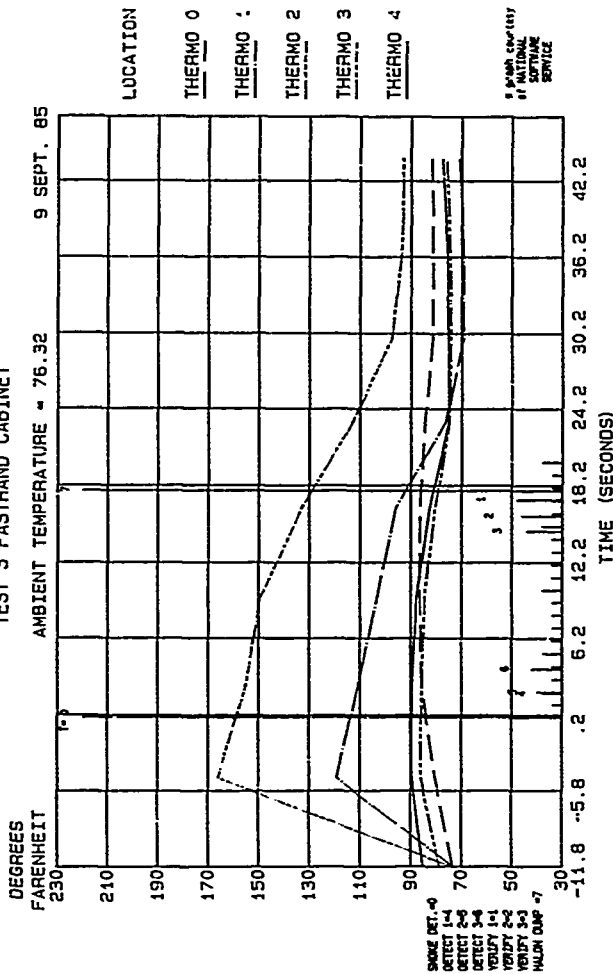
THERMO 3

THERMO 4

SAFE COMP TEST: TYNDALL AFB
COMPUTER-FIRE TEST FACILITY

TEST 4 FASTRAND CABINET

AMBIENT TEMPERATURE = 70.8   10 SEPT. 85

LOCATION

THERMO 0
THERMO 1
THERMO 2
THERMO 3
THERMO 4

TIME (SECONDS)

SAFE COMP TEST: TYNDALL AFB
COMPUTER-FIRE TEST FACILITY
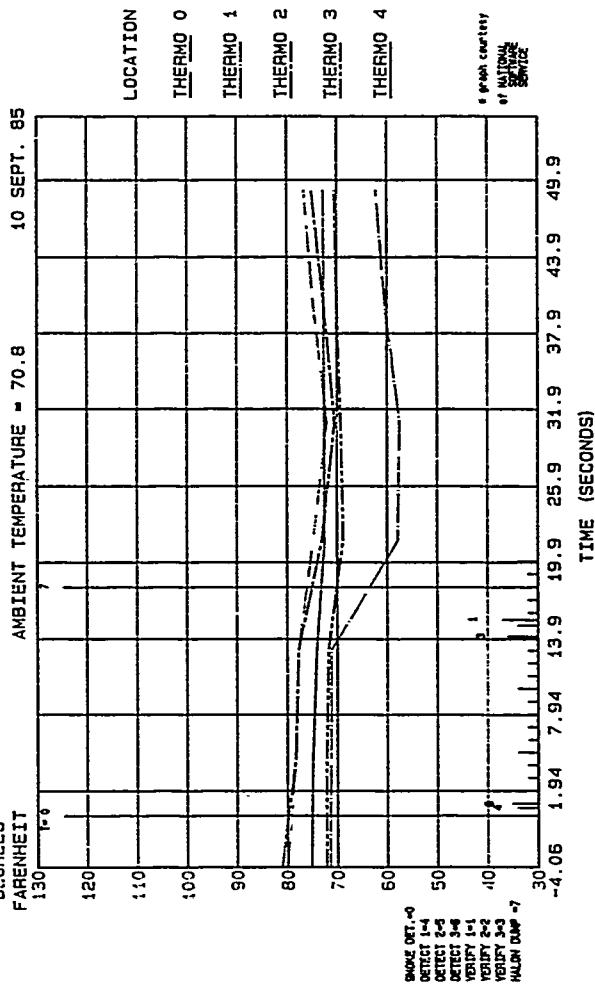
TEST 5 TAPE DRIVE CABINET

AMBIENT TEMPERATURE = 73.23   10 SEPT. 85

LOCATION

THERMO 0
THERMO 1
THERMO 2
THERMO 3
THERMO 4

TIME (SECONDS)

141
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